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A COMPUTER PROGRAM FOR SHOP SCHEDULING OF MAINTENANCE AND CONSTRUCTION PROJECTS

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A COMPUTER PROGRAM FOR SHOP SCHEDULING OF MAINTENANCE AND CONSTRUCTION PROJECTS

by

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ABSTRACT

A COMPUTER PROGRAM FOR SHOP SCHEDULING OF MAINTENANCE AND CONSTRUCTION PROJECTS

by

LT. ROBERT A. SCHADE, JR., CEC, USN

Submitted to the Department of Civil Engineering on 24 August 1964 in partial fulfillment of the requirements for the degree of Master of Science.

The purpose of this thesis is to develop a computer program for combining maintenance project schedules to economically utilize the manpower of the various skills of which a work force is composed.

Using the Critical Path Method (CPM), the program plans each project from the engineering data submitted. It then determines the most economical working schedule from a consideration of direct labor costs and indirect costs associated with the spectrum of possible schedules. Within the constraints imposed by the composition of an available work force and established project priorities, starting times of the activities comprising the projects are computed, and manpower allocations are made to effectively utilize the available labor force throughout the desired scheduling period.

Sufficient output is generated to provide top management and the scheduler with Long Range Schedule information and complete project summaries, to furnish the lead shop with detailed working schedules for each project and to list detailed master schedule information for the use of the entire work force.

The principles of Controlled Maintenance are exploited and discussed. Three program chains for CPM and related allocation computations are developed and described. The programs are demonstrated on a sample problem and excerpts of actual output as well as a Fortran program listing are included as appendices.

Work reported herein was done in part at the Computation Center at M.I.T., Cambridge, Massachusetts.

Thesis Supervisor: Albert G. H. Dietz
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CHAPTER 1

INTRODUCTION

1.1 Background

Until recently, the only formal technique of scheduling was the use of bar or "Gantt" charts that graphically portrayed the interrelationships of a project's work elements. Unfortunately, these charts were often so liberal in their approach that little more than a rough estimate of the durations of the major work elements could be determined. Little or nothing could be learned from these charts of the economics associated with the alternative working schedules. Neither did they indicate which tasks had the greatest influence on the completion time of the project. To answer these questions in addition to providing more precise information of the interrationships of different phases of the work, several new techniques were developed.

The first of these techniques originated in 1957, when consultants from the Remington Rand UNIVAC Division of the Sperry Rand Corporation were asked by the DuPont Corporation to help devise a scheduling technique to be used in the construction, maintenance, and shutdown of chemical process plants. The technique devised by James E. Kelley, Jr. of UNIVAC, and Morgan R. Walker of DuPont, is called the Critical Path Method (CPM). It is a method for achieving improved schedule and cost control over engineering projects.

In 1958, the Program Evaluation Research Task was formed by the United States Navy. The project team consisting of personnel from the Special Projects Office of the Bureau of Ordnance, the management consulting firm of Booz, Allen, and Hamilton, and the Lockheed Missile Systems Division was directed to study and formulate improved methods for the planning and control of the complex programs that were to implement the development of the Fleet Ballistic Missile (Polaris). The method developed by this group is called the Program Evaluation Review Technique (PERT). PERT is used for projects that involve research and development work in which the intellectual effort and the manufacture of component parts is new and usually being attempted for the first time. Hence, the time and cost estimates never can be predicted with adequate certainty, and probabilistic concepts are used to obtain time estimates. CPM, on the other hand, is applied to projects that are of a more deterministic nature, like maintenance and construction applications, in which costs and time estimates can be predicted with a greater amount of certainty.

At about the same time that the new management techniques, PERT and CPM, were being developed for planning, scheduling, and monitoring projects, the application of proven management and industrial engineering principles to the maintenance and operation of public works and public utilities was introduced in the Controlled Maintenance Program of the Bureau of Yards and Docks, United States Navy. The lack of planning and control and the gross

inefficiencies associated with the traditional housekeeping and breakdown methods of maintenance management had impelled its organized improvement. These motives were stimulated by phenomenal industrial advances and increases in the hourly rate paid for work performed, a rising shortage of trained maintenance personnel, and increased use of, and reliance on automatic equipment.

1.2 Purpose and Scope

Within the framework of a system of Controlled Maintenance, and utilizing the new management technique,CPM, for the planning and scheduling of the work, a computer program is developed for combining maintenance projects to economically utilize available manpower of the various skills of which a work force is composed. The scheduling system is designed to permit advance planning in the shops for the accomplishment of all maintenance projects except those which must be handled on a minor service or emergency basis due to their very nature.

1.3 Developing the Framework

First, the environment of a system of Controlled Maintenance is described. Within this context, a project is traced from inception to its final scheduling. The methodology of a planned system of maintenance management is developed.

1.4 The Scheduling Approach

With the engineering data prepared, recent developments in management scheduling techniques (CPM) and computer technology are combined to develop an approach to economically utilize a labor force of varied skills in the accomplishment of maintenance projects.

CHAPTER 2

PLANNING AND ESTIMATING

2.1 Controlled Maintenance

The basic objective of Controlled Maintenance is to obtain the most efficient use of available manpower, material, and money by: (a) increasing the productivity of the maintenance work force, (b) insuring that the standards of maintenance are at the proper level, and (c) achieving actual cost reductions in the maintenance of facilities. Five basic concepts form the basis of the composite set of integrated procedures established to meet this objective; namely, (1) organization, (2) continuous inspection, (3) planning and estimating, (4) shop scheduling, (5) reporting to management. Among the aims and purposes embodied in these concepts are:

(1) Performing maintenance on a scheduled, planned basis rather than on an intermittent, breakdown basis.

(2) Providing more direct control over the use of the maintenance labor force.

(3) Correlating the work force and work capacity of each Shop or Work Center with its work-load.

(4) Obtaining equitable distribution of shop forces.

2.2 Work Generation

To meet these aims, work requests are generated from the planned continuous inspection systematically performed by technically qualified inspectors and operators and from

the expressed observations and desires of personnel who are not part of this prescribed group of public works personnel. These requests are then screened for legality, necessity, fund and manpower availability, and scope. Following this screening action, the remaining work requests enter the planning phase.

2.2 Planning the Project

The project plan prepared by planners and estimators should specify what work is to be done, what is needed to do the work, how it should be done, and who will do the work. In terms of the Controlled Maintenance concept, this means that complete specifications will be provided, the several tasks or activities that make up the project will be described and the applicable Work Centers or Shops will be indicated. The clarity, correctness, and completeness of the project plan is crucial to accurate estimating, effective material coordination, and realistic shop scheduling.

2.3 Fundamentals of the Model

As noted previously, the planning phase consists of first determining the items of work to be performed (what), and second in what manner they can best be accomplished (how). The foundation of all modern planning and scheduling techniques and project analysis methods is the project model or network diagram.

A project can be viewed as a group of activities, jobs, and operations, performed in a certain sequence,

to reach an objective. Each one of the jobs and operations that make up a project are time and resource consuming and will be referred to as an "activity or task".

Each activity has a beginning and an end point in time that can be viewed as milestones of the project. These points in time are called "events".

A mathematical model that will satisfy the previous definitions can be visualized as a network in which circles or nodes, corresponding to events, are joined by arrows, corresponding to activities. Such a model is also a convenient way to express the sequential nature of a project.

The planning stage begins with the determination of project activities and their interrelationship. To make certain that every interrelationship is established, the following simple questions may be asked for each activity:

(1) Which activities must be completed before this activity can begin?

(2) Which activities cannot start until this activity is complete?

(3) Which other activities can be done at the same time?

The project model, project network, or arrow diagram, which is a graphical representation of the anatomy of the project,can now be constructed. Each arrow head signifies the completion of an activity, each tail the commencing of work on that activity. There is a circle or node at the head and at the tail of every activity.

2.4 Rules for Constructing the Project Model

The following rules must be followed in forming the arrow diagram to permit the subsequent application of analytic techniques in the computer program:

(1) Each defined activity is shown by a unique arrow.

(2) Arrows show only the relationship between different activities; the length and the bearing have no significance.

(3) When a number of activities terminate at one event, this indicates that no activity starting from that event may start before all activities terminating at that event have been completed.

(4) If one event takes precedence over another event that is not connected by a specific activity, a "dummy" activity is used to join the two events. Dummy activities are usually represented by dashed arrows on the arrow diagram.

(5) Events are identified by numbers. The nodes must be numbered such that no two nodes have the same number. Each event or node should be identified by a number sequentially higher than the immediately preceding event.

(6) The network must have a single starting event or origin and a single terminus or ending event.

(7) Activities are identified by the numbers of their starting event and ending event. (In addition, an identification number is assigned to each activity, as well as to each project).

2.5 Levels of Detail in Arrow Diagramming

There is no such thing as "a" model to represent a given project. An activity, it is recalled, is a meaningful segment or unit of work that can be accomplished without interference or interruption from any other work. The planner develops an activity list by examining the description of operations involved. In some instances, a single operation is an activity, and in other instances, an activity may consist of a number of operations or an activity may be subdivided. The degree to which steps are combined or subdivided will depend upon the work directly involved, the type and amount of related work involved, and the degree of coordination required.

2.6 Estimating the Project

With the project activities plotted according to the arrow diagramming technique described in the previous sections, it can be seen that numerous paths exist between the initial node and the terminal node of the project network. By estimating the time it will take to complete each activity, (duration, D_{ij}), and adding the duration of all the activities forming a path, various "durations for project completion" are obtained. The longest of these durations is the critical time for project completion, and the path associated with it is the "critical path". The critical path controls the project completion time.

Estimating, then, is the informed analysis of all the known and probable elements of a proposed project

and the resulting forecast of the manpower and related requirements that will be needed to accomplish the project.

2.7 Estimating Activity Durations

For purposes of estimating durations, activities are broken into the following categories:

(1) Dummy activities - duration is zero. Therefore neither men nor cost is involved.

(2) Activities of known rates of production - duration is determined from accumulated experience data and engineered performance standards. For example, one carpenter can install one doorframe per hour. An activity to install a doorframe would have a duration of one hour if one carpenter were used. However, if two carpenters were used, developed standards might indicate that a doorframe could be installed in two-thirds of an hour. This accelerated working rate has reduced the activity duration, but at the sacrifice of economy for one and one-third man-hours have been expended in the installation of a single frame. This is the principle utilized in the computer program. To simplify the work of the estimator, the activity durations are computed by the program from the man-hours requirement of the activity and the total work crew assigned.

The formula used is:

AD = MH/(0.5 x WHPD x WRKRS)
where: AD = Activity duration
MH = Activity MAN-HOURS required
WHPD = Working hours per day
WRKRS = Total number of workers on activity

Activity durations are rounded to the nearest half day. Two different manning teams are permitted, one to work the task at a standard rate, and the other at a crash rate. It is assumed that an activity can be worked at either rate. At the standard rate, maximum worker productivity results. The crash rate, on the other hand, is faster but less efficient and therefore a more costly working rate. However, if applied to critical activities, it results in a shorter project working time and consequent reduced indirect costs. This is discussed in more detail in a later chapter.

(3) Activities of specified duration - for example, the project specifications may require that "concrete will be allowed to cure for x days before bearing vehicle traffic".

(4) Material required - activities to represent material deliveries are not included in the arrow diagram which is used solely for manpower allocation. Rather, material deliveries are estimated and projected availability is utilized to determine the point at which project scheduling will be permitted.

(5) Other activities - this includes those types of work for which no engineered performance standards exist. Here, all available information must be obtained and an estimate formulated.

Time estimates, for purposes of this program, are prepared in terms of half days. However, there is nothing inherent in any of the analytic techniques which prohibits the use of hours, integer days, or weeks, except that all times must be in like units.

2.8 Summary

The planner and estimator is (are) responsible for preparing the project activity data used by the scheduler as a portion of the program input. The data contains the basic engineering, identification, and economic information of work to be accomplished. As described heretofore, this includes the project and activity identification numbers, the activity initial and terminal node table determined from the arrow diagram precedence requirements, the number of man-hours of work for each task, the number of men required of each skill for each manning team, and the associated costs.

CHAPTER 3

ACTIVATING THE PROJECT

3.1 Reviewing the Project Plan and Estimate

The impact of the project plan on the Shops is of such importance that the manager of the Planning and Estimating Branch should carefully examine the completed plan and estimate before transmitting it for approval. This review should insure that the final plan and estimate is complete, accurate, lucid, and in conformance with established policies.

3.2 Managing the Backlog

Upon completion of the final estimate, steps should be taken to activate the project. These steps include the preparation of the Project Order for authorization and determining the timing for issuing the Order to the Master Scheduler. These steps together with those that determine the type of performance and those that affect balancing of shop forces, may be termed Managing the Backlog.

3.3 Determining Type of Performance

The determination must be made as to whether the entire project or parts of the project should be done by outside contractors. This decision is based on the urgency of the work, the capacities and facilities of the shops to do the proposed work and, in some cases, the comparative price.

3.4 Timing

Issuance of the Project Order may be deferred to meet budget considerations and more favorable seasons or weather. Maintenance of equipment and facilities during idle or offpeak seasons is another aspect of timing in project management.

3.5 Priorities

There are two basic areas of maintenance, each requiring different handling. The first area comprises emergency service and minor work generated by reasons of safety, breakdown, and so forth, or so classified because of the scope of work. Such work is expeditiously completed by personnel designated for that purpose. The second distinct area consists of Project Orders where the work exceeds the limitation set for minor work. This work has been the subject of this thesis and must be planned, estimated, scheduled, and performed in an orderly, routine, and efficient manner.

The program determines the relative priorities for completing submitted Project Orders from the indirect (opportunity, overhead, downtime) cost assigned during this phase of the project management. This assumes that management objectives for scheduling are for accomplishment of each project with minimum total expense. However, management may dictate other objectives such as a directed starting or completion time or a shortest time plan involving crash methods. The indirect cost must be carefully assigned so as to fulfill the management objectives, whatever they may be.

3.6 Project Authorization

The completed staff work is submitted for project authorization to the designated representative of the firm involved. This person reviews and approves in writing the plan and estimate data on the Project Order and the indirect cost designation used to determine the project priority.

3.7 Material Coordination

Under the principles of Controlled Maintenance, material coordination is achieved during the planning and estimating phase, by specifying the types, qualities, quantities, and costs of material required for each project and during the project management phase by requisitioning and expediting material procurement. As soon as material availability for an authorized project has been determined, the Project Order is released for shop scheduling.

3.8 Summary

During the period of project activation, the plan and estimate for each project is meticulously examined, the type of performance and the timing are determined, the indirect cost is assigned, the project is authorized, and the availability of necessary materials is established. The Project Order is then released for shop scheduling.

CHAPTER 4

SCHEDULING

4.1 General

Shop scheduling is the means of committing shop personnel to specific work sufficiently in advance of accomplishment to assure coordination of the men, material, and equipment. This is necessary to achieve maximum efficiency of job performance. Shop scheduling is a carefully prepared advance plan of action that has taken into consideration the availability of manpower, materials, and equipment; the proper sequence of work operations; the proper sequence of the crafts necessary to perform these operations; and the most economical force to be assigned to the various operations making up the complete project. Generally, the projects are released for scheduling in the order they are received. However, projects requiring material procurement are not released until the date of material availability has been established. The exact order in which projects are scheduled is contingent upon the need for the work in relation to the mission of the installation (priority); the availability of manpower, material, and work sites; and the seasonal characteristics of the work. Effective shop scheduling when properly performed provides for the orderly and economical accomplishment of projects, as well as the orderly introduction of work into the various Work Centers. Flexibility must also be provided to absorb urgent work and other unforeseen events arising

in the performance of maintenance work. This manpower cushion is obtained by adopting a combination of two scheduling systems: Master Project Scheduling and Work Center Scheduling.

4.2 Committing Work

Master Project Scheduling firmly commits, to major jobs, 75% of the shop forces available. This 75% is scheduled on both the Master Project Schedule and the Work Center Schedule. The remaining 25% of the available shop force is scheduled for minor service or emergency work on the Work Center Schedule only. This 75%-25% ratio is not rigid. When several emergency projects arise simultaneously or a large backlog of minor service work develops in a Work Center, it may be necessary to temporarily reduce the ratio to 70%-30% or 65%-35%. If the minor service work backlog becomes low, more men may be made available for Master Project Scheduling.

4.3 Master Project Scheduling

Master Scheduling establishes an organized and coordinated plan for the accomplishment of major jobs. It is the principal subject of this thesis. A computer program is developed to firmly commit specific Work Centers to specific projects for specific periods of time. Once the plan developed by the program has been accepted, adherence to the schedule should be mandatory to assure that the work progresses in the most economical manner. The Master Schedule should not be adjusted to meet minor changing job conditions or actual performance deviations. The Master

Schedule should be changed only when there is a major change in the scope of the work; when major delays occur as a result of the nondelivery of material when anticipated; or when the entire schedule is disrupted by emergency conditions.

The Master Scheduler is responsible for the proper format preparation of program input data. As each specific Project Order is received, he initiates action toward final scheduling of that particular job. This includes preparation of project and activity data cards for each project and a master card deck for each program run. The Master Scheduler must ascertain the availability of manpower in each Work Center. He assigns a lead shop to all those projects which in his opinion require activity coordination. Further, the Master Scheduler is responsible for proper and complete dissemination of program output for top management and shop use. He is also responsible for assuring that projects with major changes or delays are re-engineered and re-submitted to the computer for necessary scheduling adjustments.

4.4 Work Center Scheduling

It will be recalled that only approximately 75% of the work force is made available for Master Scheduling of specific Project Orders. The remaining 25% are scheduled by the Work Center supervisor on minor service or emergency work. If an emergency project is imposed on a shop after the Master Schedule has been prepared, then the scheduled minor work, not the committed major projects, are interrupted to make the necessary manpower available for the emergency. The Work Center schedule, which indicates the

Master Scheduling accomplished by the computer program and the minor service work scheduled by the Work Center Supervisor, accounts for the entire work force of a Work Center. It keeps the shop personnel informed as to which tasks they are to work and provides manpower availability information to the Master Scheduler.

CHAPTER 5

PROGRAM TECHNIQUES

5.1 General

This chapter presents a synopsis of the methods used in the three program chains:

Chain 1: Determining the Critical Path for each project and the most economical Working Schedule.

Chain 2: Allocating total manpower to priority projects.

Chain 3: Determining activity event times to utilize the available Work Force.

5.2 Chain 1

A. General

After the master input card and the project identification and accompanying activity data cards have been read into the computer, the program determines a working schedule for each newly submitted project using the Critical Path Method (CPM).

B. Critical Path Technique

It will be recalled that during the planning and estimating phase, an arrow diagram of the project was prepared, and an estimate of the man-hours it would take to complete each activity with two different work crews was made.

From this information can be found the earliest and latest possible times for the occurrence of an event, or the earliest and latest times for the start and termination of an activity. It is noted that an event occurs only when all the activities terminating at that event are completed.

Because events and activities are very closely related, they will be treated integrally. Let (ij) represent an activity that is in a project. The beginning of activity (ij) is denoted by the event (i), and the end of the activity is denoted by the event (j). The duration of the activity (D_{ij}) represents the time associated with the performance of an activity.

Relative to a project start time and completion time, each event has an earliest event time (EET_j) and a latest event time (LET_i).

In the general case, it is possible to have more than one activity coming into an event. Because event (j) occurs only when all activities terminating at (j) are complete, the earliest occurrence of an event (j), EET_j, is

$$EET_j = \max [EET_i + D_{ij}]$$

in which $i < j$.

Similarly, denoting the occurrence time of the terminal event in a project by the latest occurrence of an event (i), LET_i, and defining it equal to its EET,

$$LET_i = \min [LET_j - D_{ij}]$$

in which $i < j$.

In scheduling activities four terms are of interest. They are the following:

(1) Early start
(2) Late start
(3) Early finish
(4) Late finish

Early start (ES) is defined as the earliest point in time an activity can be started if all preceding activities are completed as scheduled.

$$ES_{ij} = EET_i$$

Late start (LS) is defined as the latest point in time an activity can be started without delaying the scheduled completion of the project.

$$LS_{ij} = LET_j - D_{ij}$$

Early finish (EF) is defined as the earliest point in time an activity can be finished if all preceding activities are done in their scheduled durations.

$$EF_{ij} = EET_i + D_{ij}$$

Late finish (LF) is defined as the latest point in time an activity can be completed without delaying the scheduled completion of the project.

$$LF_{ij} = LET_j$$

To facilitate analysis, it is necessary to introduce a concept that concerns itself with the lag that may occur on certain activities during a project without affecting the over-all project duration. In CPM, this is referred to as "float" or "slack". There are four types of float only one of which is of concern in this thesis.

Total float (TF) is defined as the maximum amount of time the scheduled duration of an activity can be lengthened without delaying the scheduled completion of the entire project. It is the difference between the latest and ear-

liest finish, or the latest and earliest start.

$$\begin{aligned} TF_{ij} &= LET_j - EET_i - D_{ij} \\ &= LF_{ij} - EF_{ij} \\ &= LS_{ij} - ES_{ij} \end{aligned}$$

Float is often considered as the measure of the criticalness of an activity relative to the project as a whole. When the maximum available time equals the duration of an activity or, in other words, when an activity has zero total float, that activity is termed "critical". Any increase in the time required for such an activity will result in a corresponding increase in the duration of the entire project. In a project, there are one or more paths from origin to terminus on which this condition prevails. This path(s) is termed the "critical path". The critical path is defined as the longest time path from the initial to the terminal event in a network.

In the program a systematic method for determining the critical activities is used. The algorithm[1] consists of establishing the earliest event times and the latest event times for all the events and applying a simple test to determine if an activity lies on the critical path. An activity,to be critical, has to meet the following conditions:

---

[1] An algorithm is a mathematical technique which can be advantageously utilized to solve a particular problem. Inherent in most algorithms are specialized notation and a formal set of procedural rules.

The activity's (i) event and (j) event must be critical events, and

$$LET_j - LET_i = EET_j - EET_i = D_{ij}$$

By applying these simple tests to all the activities, the critical activities giving the critical path(s) for all newly submitted projects are determined. The working schedules of all previously submitted projects are retained on a project carryover tape and need not be recomputed.

C. Project Cost Curve and Working Schedule

To get the full benefit of a project management system, there is another factor that should be considered: Optimization of an objective such as cost or resources.

The use of the standard activity durations for all activities may not always be satisfactory. To reduce the total project duration, resorting to a more costly schedule may be necessary. A common practice in project management has been to apply extra effort to all activities in order to obtain the compression in schedule. However, concentrating on activities that are on the critical path is more fruitful, because any reduction in a critical activity (provided that it lies on the only critical path) results in a corresponding reduction in the total project time. The goal in carrying out this project crashing process is to keep the cost increase to a minimum.

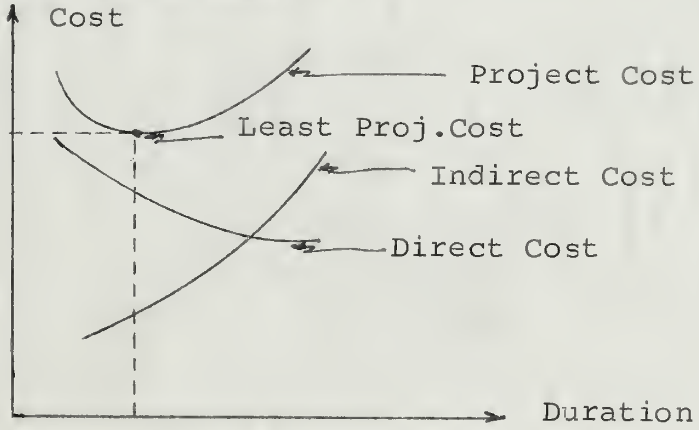
To provide this operating flexibility, the program permits one of two manpower teams to work each project

activity. One team would work the activity on a standard basis (Standard Duration, SD) at which the greatest worker productivity results. Accordingly, this basis is the most economical from the standpoint of direct labor costs. The other team would work the task on a crash basis (Crash Duration, CD) which results in the shortest feasible activity working time.

In general, crashing the time of an activity results in a higher direct labor cost because of declining worker productivity. However, crashing the working times of critical activities produces a shorter project duration with a lower project indirect cost.

A spectrum of project durations is possible from standard manning (SD) on all activities to crash manning (CD) on all critical activities. The project working schedule with the least total costs (sum of direct labor costs and indirect costs) is determined from these schedules for actually working the project.

To formulate criteria for the procedure, it is necessary to provide cost data for the duration of standard (Standard Cost, SC), and crash (Crash Cost, CC) activities. The costs associated with a project may be graphically shown as follows:



The right-hand limit is the project working time that results from standard manning (SD) on all activities. The minimum point of the project cost curve (sum of direct and indirect costs) defines the most economical project duration possible.

To determine this point, standard manning (SD) is initially used on all activities. To shorten the project duration, critical activities are crashed one by one. In making the time reductions in the critical activities, those reductions that have the smallest incremental increase in direct labor costs (IC) are sought. This can be represented mathematically:

$$IC = CC - SC/SD - CD$$

The critical activity with the smallest value of IC is crashed first. A new schedule for the whole project and the project cost curve are then determined.

This process of crashing critical tasks one by one continues until the entire project cost curve has been found. The activity manning team configuration that resulted in the minimum project cost is then utilized for actually working the project.

It might appear that a simpler approach would be to start at the right of the project cost curve and compute new project durations only as long as the project cost curve is decreasing. However, two or more critical chains may exist in the project at the same time. If this were so, merely crashing one would produce higher direct labor costs but would not reduce the project duration and the indirect costs. Therefore, several minima may exist on the project cost curve and the entire curve must be

generated to assure determination of the most economical project working schedule.

This process is repeated for each newly submitted project. Once established, the project duration, manning configurations, and activity working times are not altered.

It is pointed out that this means of determining the least cost schedule is not the only technique for doing so. Other methods allow an activity's duration to vary between its standard and crash working times. The cost of crashing varies linearly between these two limits. A linear program is then used to determine the optimum durations of the activities given a fixed project working time. These methods were not used here since variable activity durations would have resulted in fractional manpower requirements. It was felt that this was not in keeping with the development of a practical operating program.

D. Data Modification and Transfer

Before the least cost working schedules can be written on the input tape for the next program chain, several modifications are made to some of the data.

It will be recalled that the non-critical tasks possess a workable range because of their float. To enable the scheduling routine in Chain 3 to take advantage of all the float before having to work non-critical activities, new variables for best start and best finish are equated to the activity latest start and latest finish respectively. In addition, another modification is made to the earliest

start and the latest finish of each activity. These variables were determined in terms of the event node numbers rather than the assigned activity identification numbers. From the standpoint of program running efficiency, however, it is more desirable to have them indexed in the same manner as the other activity variables. Therefore, a conversion routine is included to re-define earliest start and latest finish in this manner.

Another routine is also included to delete the superfluous values in the activity skill variables. There are two activity variables indicating manpower utilization for each skill. However, once the appropriate manning team has been determined for an activity, half of this information is no longer required. Accordingly, a routine has been developed to delete the extra variable for each skill and use the correct manning team on each activity. The activity incremental cost serves this purpose for whenever crash manning is to be used, the program causes the IC value for that activity to be made negative. A test is then made of the sign of IC to determine which manning basis to use.

After the project start and finish are initialized, the data for each project is written on tape to serve as input for the following program chains. Basic project information is written on one tape for Chain 2 use and the activity schedules are written on another tape for use in Chain 3.

E. Carryover Projects

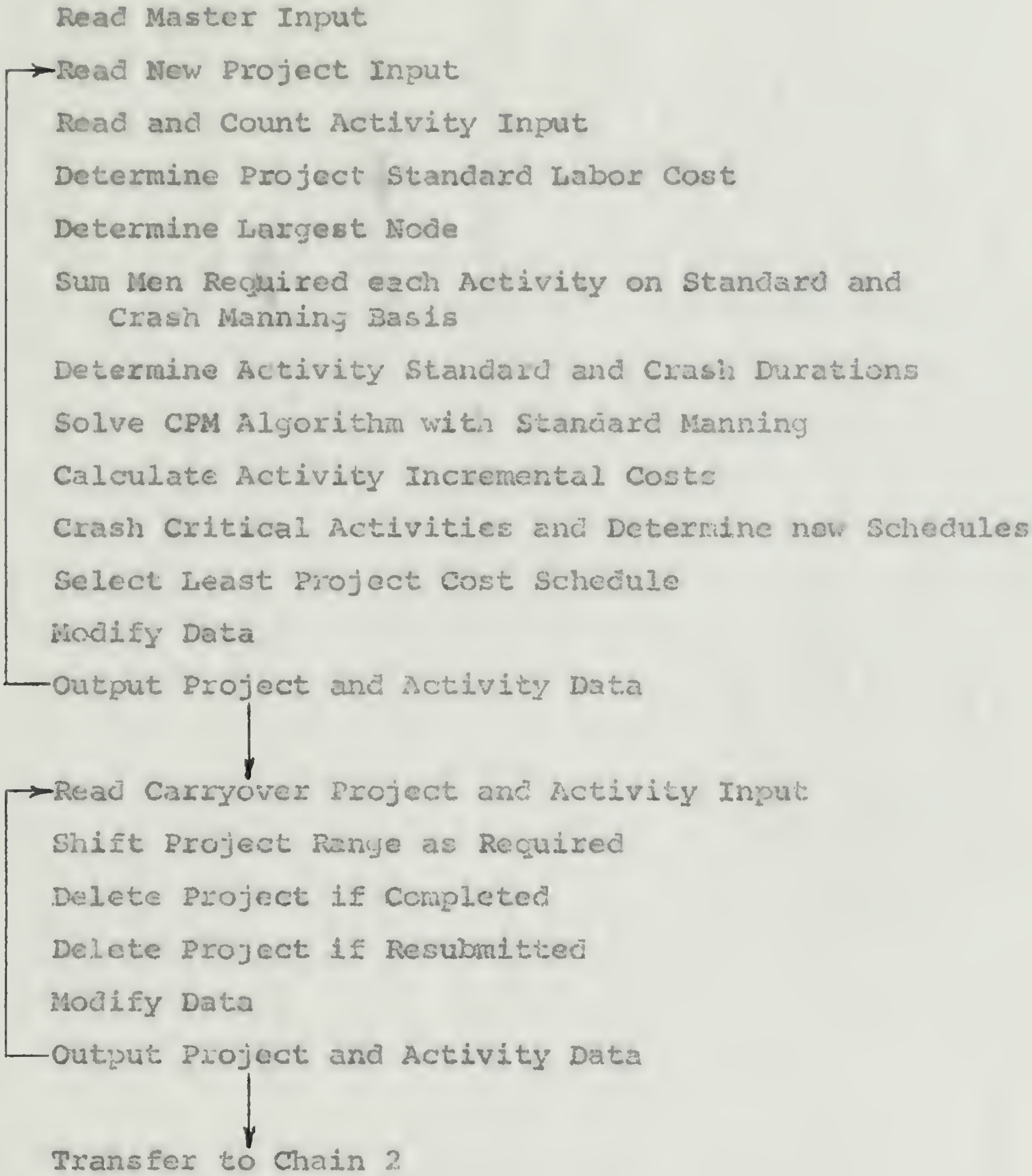
After all original projects have been processed, carryover projects are then manipulated. The first project working schedule is read from the carryover tape. First, it is determined whether to shift projects to keep them within range of the computed schedules output. Whenever the desired starting day for the output schedules shifts from the end of one year to the beginning of the next, all old project working schedules must also be shifted. Next, its finish is compared with the master variable schedule start to determine whether the project is to be deleted. If the test shows that the project is scheduled to be finished prior to the desired scheduled start of the current output, the project will be deleted. Another test is performed to compare the carryover project identification number with the identification numbers of newly submitted projects. If the same number is encountered, the carryover project data is deleted, thereby preventing the project from being scheduled twice.

The carryover information remaining is then written on tape for later program chains and control is transferred to Chain 2.

F. Summary

To present an overall picture of this program Chain, a simplified flow chart is presented on the following page.

FLOW CHART OF CHAIN 1



Read Master Input

Read New Project Input

Read and Count Activity Input

Determine Project Standard Labor Cost

Determine Largest Node

Sum Men Required each Activity on Standard and Crash Manning Basis

Determine Activity Standard and Crash Durations

Solve CPM Algorithm with Standard Manning

Calculate Activity Incremental Costs

Crash Critical Activities and Determine new Schedules

Select Least Project Cost Schedule

Modify Data

Output Project and Activity Data

Read Carryover Project and Activity Input

Shift Project Range as Required

Delete Project if Completed

Delete Project if Resubmitted

Modify Data

Output Project and Activity Data

Transfer to Chain 2

5.3 Chain 2

A. General

One of the major outputs of this Chain is a long range schedule of daily manpower utilizations. This output provides the Master Scheduler a means of determining daily manpower allocations among the projects for the duration of the schedule. It also conveys the project working times and working priorities for the information of top management. The computations of this schedule and the nature of its parameters form the substance of this Chain.

B. Project Priorities

After the basic project data prepared by Chain 1 has been read into the computer, project working priorities must be determined.

Previously scheduled uncompleted projects receive first priority to enable them to be continued without interruption to completion. The priorities of other projects are determined according to the criterion that marginal workers are utilized on those projects which provide the greatest indirect cost savings. Thus, where:

PP = Project Priority
EV = Economic Value (loss per day)
PAWF = Project Average Work Force
and PP = EV/PAWF,

the higher the value of PP for a project, the higher is its priority.

There are two restrictions imposed concerning the work force composition. First, the total manpower availability

must remain unchanged for the scheduling period. Second, the distribution of men among the Work Centers or skills must likewise remain constant for the same period.

The reason that these priorities are considered necessary is the assumption that there will be more projects than men to work them. A selection criterion is therefore proposed to schedule the "better" projects first. It is stressed that this rationale is purely arbitrary though intuitively logical. The Master Scheduler may desire to give any new or re-engineered project priority over all other projects including projects being worked. To accomplish this objective, the Master Scheduler would:

(1) Resubmit to the program as new data all working projects that the Scheduler desires to stop in favor of the more valuable project. Of course, only those activities which have not been completed should be resubmitted.

(2) Submit the valuable project with other new project data, being certain that the economic value (loss per day) assigned is so high as to give that project a very high priority according to the economic selection rationale.

This procedure frees sufficient personnel to assure the valuable project is accomplished. However, those projects that were previously working lose their first priorities and have to compete for priorities with other newly submitted projects and unscheduled carryover projects.

C. Manpower Allocations

When all project working priorities have been determined, total manpower allocations can be made to the projects. The following procedure is employed:

(1) On the half day being scheduled, assign to each project a number of workers equal to the project average work crew.

(2) Continue allocating manpower in the above manner until the remaining work force is less than the average manning team of the next priority project.

(3) Add men to the previously scheduled projects one man at a time to each project until the number of men remaining to be scheduled is zero.

(4) Repeat the above process for successive half days until the entire range has been scheduled.

Once a project has been started, it is worked continually until completion. Therefore, critical activities have rigidly defined starting times. Because of their workable ranges, non-critical activities have variable starting times. As such, project daily manpower requirements may be manipulated through different scheduling combinations of the non-critical activities.

Although this allocation procedure is not as flexible as might be desirable, it is used because of its relative programming simplicity. Further, if projects were to be scheduled initially at less than their average work crew, greater manpower demands would later occur. If several projects were so scheduled, a potential manpower overflow could result. Such a schedule would be infeasible since the manpower requirements would be greater than the available labor force.

Projects are worked in the order of their priorities. Therefore, in step 2 of the procedure, the average manning teams of other projects are not tested when the next

priority project cannot be worked. It is felt that it may be desirable to schedule projects initially at less than their average work force. Such a procedure would require a routine to estimate future work force utilization in addition to present usages of the half days being scheduled. This situation, although a programming possibility, would result in countless complications and is felt to be beyond the scope of this thesis.

It is also noted that the long range schedule allocates the labor force among the projects without access to their particular activity manning configurations. In all likelihood, the projects will not actually be worked at the rate prescribed by the long range schedule. The real purpose of this schedule is to serve as a guide not only to the Master Scheduler and management personnel, but also to program Chain 3 where the men are assigned according to skills. Although the detailed scheduling attempts to follow the long range allocations, activity manning configurations preclude following them exactly. Modifications are therefore made to permit the establishment of a feasible working schedule.

D. Transfer of Data and Control

Project summary and long range output listings are prepared by this Chain and basic project information is placed on tape as input for the last program phase. Control is then transferred to Chain 3.

E. Summary

To provide an overall picture of the discussion of this section, a simplified flow chart is presented on the following page.

FLOW CHART OF CHAIN 2

Read Input Data from Tape

Assign Priorities to Working Projects

Calculate Priorities of other Projects

Assign total Manpower to Projects

Output Long Range Schedule

Output Summary of Projects

Output Project Data for next Chain

↓

Transfer to Chain 3

5.4 Chain 3

A. General

The principal purpose of this program is to develop detailed working schedules for the Work Centers or Shops. This part of the program provides detailed working schedules for each project for the use of the lead shop, and lists detailed master schedule information for the use of the entire labor force. The program techniques used in the preparation of these listings are discussed in this section.

B. Consolidate Project and Activity Data

In order to establish actual (best) activity starts of non-critical activities possessing workable ranges, the basic project information output of Chain 2 must be merged with the activity schedules developed by Chain 1. Project and activity information is continually read from two tapes, consolidated, and written on a third tape for use in determining activity event times.

C. Locate the Project to be Scheduled

Once the project and activity data has been merged, the tape must be searched to determine the correct project to be scheduled.

To eliminate much of the inefficiency inherent in tape searching, a series of numbers were assigned to determine the working order of the projects. Specifically, the series was prepared so that the first number equalled the relative position of the first project to be scheduled, etc.. Thus, if the first number were 8 and the second

number were 5, this would indicate that the first project to be scheduled was the eighth one on the input tape and the second project was the fifth one on the tape. These numbers, therefore, tell the program how many projects to skip before the correct project to be scheduled is read. Likewise, after a project has been scheduled, the next number tells the program whether to rewind the tape before searching for the next project or to continue searching without rewinding.

D. Determine the Starts of Non-Critical Activities

When the correct project has been located and read into the computer, a restriction on the starts of non-critical activities is determined from the earliest starts and the latest finishes computed in Chain 1. This restriction must be found since activities that occur later in a network path are blocked by earlier activities in their respective paths. For any activity, the restrictive start is equal to the latest actual (best) finish of any previous connecting activity.

E. Determine Work Force on Working Tasks

With the restrictive start of each activity computed, the program selects the first half day to be scheduled and determines the number of men of each skill:

(1) Working on critical tasks.

(2) Working on previously scheduled, uncompleted non-critical tasks.

(3) Needed to work non-critical tasks whose latest starts are equal to the half day being scanned. These tasks must be worked since a further delay in working

them would increase the project duration.

Since the above activities must be worked on the half day being scheduled, some skills may be used at a rate greater than their proportional share of the available work force. The cumulative difference (CD) between the proportionate share of a skill and the actual number of workers of that same skill who are scheduled is therefore calculated after all working activities have been determined. This deviation is compensated for in the selection of other non-critical activities to be scheduled on the same half day.

F. Schedule Non-Critical Activities

When the number of workers scheduled on the half day being scanned is less than the number allocated by the Long Range Schedule, other non-critical activities are scheduled. To determine which non-critical tasks should be worked in their workable ranges, a selection criterion was sought which would yield a good practical working schedule and yet be self-compensating in that when deviations from proportionate skill shares occurred, they would be immediately compensated for in the selection of the next activity.

The rule utilized is that the non-critical task whose actual skill requirement is closest to the proportionate share of the skills that the task requires, will be scheduled. For example, assume a work force of 60 men: 40 of skill 1 and 20 of skill 2. Further, assume that all workable tasks require a total of 6 men each. The proportionate shares of the skills would then be 4 of Skill 1 and 2 of Skill 2. The task whose actual skill requirement is closest

to these proportionate shares will be scheduled.

Since no task may conform exactly to this requirement, deviations between the proportionate shares of the skills and the actual skill requirements are recorded and added to the shares of the next activity to be selected. In the case above, assume that the activity actually scheduled required 5 men of Skill 1 and 1 man of Skill 2. The deviations would be - 1 for Skill 1 and +1 for Skill 2. Thus, for the next activity, the desired skill configuration would be 3 men of Skill 1 and 3 men of Skill 2.

All 60 men are scheduled in this way. In order to use the total manpower available, however, the last activity in the last project may have to assign some men out of skill. The Master Scheduler would then have to decide whether such assignments were permissible or whether to resubmit the activity during the next schedule run and permit these workers to be scheduled in the Work Centers on minor Service and emergency work.

To select the non-critical task the following mathematical formula is used:

$$V = \sum_{1}^{N} \left| \frac{W}{TWA} \times S + CD - WR \right|$$

where: V = Value of the task in question
W = Total number of workers required by the task
TWA = Total workers available
S = The workers available of a skill or from a shop
CD = Cumulative difference (defined above)
WR = Workers of a skill required by the task
N = Number of skills of which the work force is composed

The task with the lowest V is selected since it results in the least number of men being scheduled out of skill on the proportionate share criterion utilized. It is noted that the prescribed network sequence may preclude working some of the activities. After a task has been scheduled the restricted starts of following tasks are adjusted.

The above process is repeated until the number of men scheduled for the half day being scanned is equal to or greater than the number allocated, or until no more men can be scheduled because of the precedence requirements imposed by the project network.

G. Schedule Control Variances

It is recalled that the Long Range Schedule assigned the total work force for the half day in question. If the actual detailed manpower utilization determined above differs from the original allocation, such deviation is recorded and an attempt is made to compensate for the difference. For example, assume the 60 man labor force of the previous illustration had been allocated by the Long Range Schedule, 40 men to project 1 and 20 men to project 2. If the detailed routine scheduled 43 men to the first project, the program, to stay within the total manpower availability would schedule only 17 men for project 2 in lieu of the 20 originally assigned.

The above procedure, however, has caused the first project to be over-worked and the second to be under-worked. The program records these variances and attempts to compensate for them in the next half day scheduled. Thus,

in this illustrative example, the program would try to assign 37 men to project 1 and 23 to project 2.

From the above, it is apparent that the detailed schedule routine of this Chain attempts to follow the original schedule developed in Chain 2 as closely as possible. It compensates immediately for any deviation introduced into the project working rates to assure that all work is completed on time, and that the entire work force is utilized.

H. Project Processing

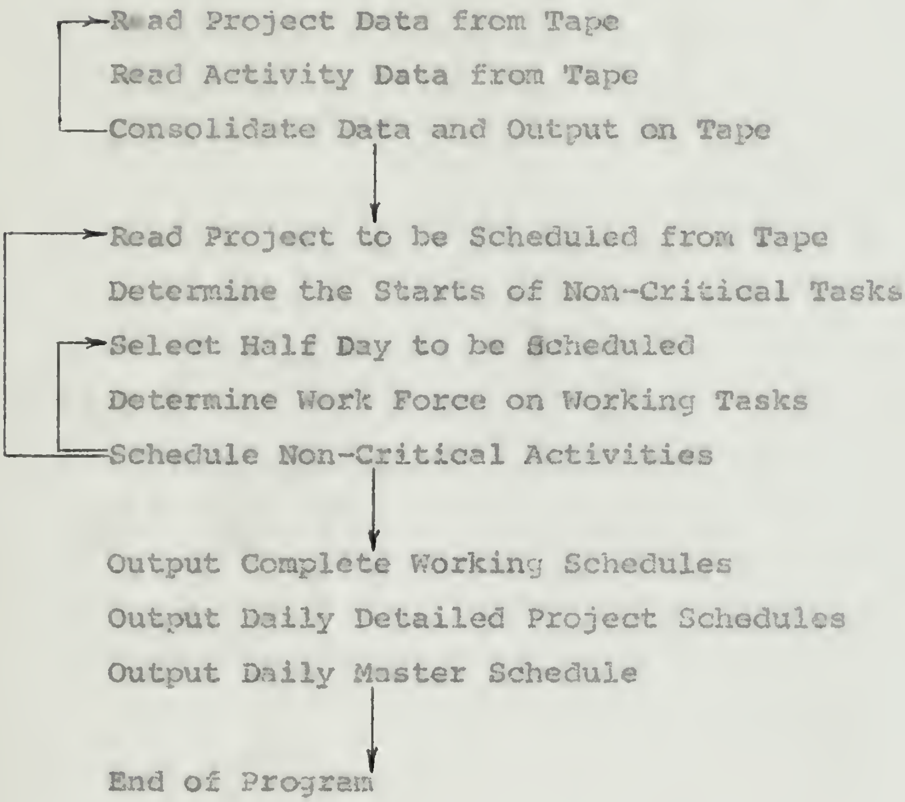
Succeeding half days are selected, one at a time, and the above procedures are repeated until the project working schedule for the entire specified range has been determined. Succeeding projects are then selected according to the series of numbers determining their working order and scheduled in the same manner.

I. Summary

To provide an overall picture of the steps performed in Chain 3, a simplified flow chart is presented on the following page.

As further clarification of the techniques used in Chain 3, an example of the process of detailed scheduling, is presented in Appendix A.

FLOW CHART OF CHAIN 3


Read Project Data from Tape
Read Activity Data from Tape
Consolidate Data and Output on Tape
Read Project to be Scheduled from Tape
Determine the Starts of Non-Critical Tasks
Select Half Day to be Scheduled
Determine Work Force on Working Tasks
Schedule Non-Critical Activities
Output Complete Working Schedules
Output Daily Detailed Project Schedules
Output Daily Master Schedule
End of Program

CHAPTER 6

PROGRAM INPUT FORMAT

6.1 Program Input

The program requires three different types of input:

(1) Master Schedule Parameters

(2) Project Identification

(3) Activity Data

Because of the volume of data handled by the program, six different tape units are utilized. They have been assigned to be consistent with the Fortran Monitor System (FMS) used at M.I.T. Tape units are designated as follows:

Physical	Logical	Function
A2	4	New program data inputs
A3	2	Printed output
A4	8	User scratch tape used by program chains
B4	3	Primary chain tape for program storage
B5	9	User tape for intermediate input and output between chains
B5	10	User tape for intermediate input and output between chains. Also used for carryover data to be retained for future scheduling

All tapes are rewound automatically as required by the program. Since Tape Unit 2 carries the printed output, it must not be rewound until all program Chains have been completed.

(1) Master Schedule Parameters

The purpose of these parameters is to provide the Master Scheduler with adequate control of the program

operation. The format and purpose of these variables are as follows. Each should be right justified in its respective field.

Card Columns	Format	Information
1-4	Integer	Schedule Start: the first day of the scheduling period.
5-8	Integer	Long Range Schedule Range: determines time range in working days of the long range schedule. It must not be larger than the number of working days in a year. Normally, this range would be between 2 and 3 months.
9-12	Integer	Detailed Schedule Range: determines time range in working days of the detailed schedules. It must not be larger than the Long Range Schedule range nor the number of working days in a year. Normally, this range would be between 2 weeks and 1 month.
13-16	Integer	Working Days Per Year: Must not be greater than 360 days.
17-20	Integer	Working Hours Per Day:
21-24	Integer	Schedule New Year Shift: required to shift working projects from the end of one year to the beginning of the next whenever Schedule Start is the beginning of a new year. A 1 should be indicated in such cases. At other times of the year, enter a 0.

25-28	Integer	Project Carryover: conveys to the program if there is project carryover data from a previous run. If there is project carryover, enter a 1. When there is no project carryover data (such as in the first run of the program) enter a 0.
29-32	Integer	Skill 1 Availability: tells the program how many men of this skill are available. Numbers have been used in lieu of titles or Work Center affiliation. The number of men available of each skill must remain constant during the range of the printed output.
33-36	Integer	Skill 2 Availabilities
37-40	Integer	Skill 3 Availabilities
41-44	Integer	Skill 4 Availabilities
45-48	Integer	Skill 5 Availabilities

(2) Project Identification

The purpose of these inputs is to identify the project for subsequent printout and to allow the Master Scheduler to control the working order of the projects through a measure of economic value. Each variable should be right justified in its respective field.

Card Columns	Format	Information
1-5	Integer	Identification Number: identifies each project for printed output. Use any number between 1 and 32,786
6-10	Integer	Project Economic Value: represents the indirect costs per day (loss) of not working the project.

(3) Activity Data

The activity data input, prepared by the planner and estimator, provides the basic engineering information necessary for scheduling the activities by CPM. Each variable should be right justified in its respective field. All are required for each activity. One activity is punched per card. The field of a variable with zero value may be left blank.

Card Columns	Format	Information
1-5	Integer	Identification Number: identifies each activity in a project for printed output. Use any number between 1 and 32,768. Activities can be numbered according to shop or Work Center, skill, or lead shop.
6-10	Integer	Initial Node: represents the initial node to which the tail of an activity connects. Nodes should be uniquely numbered between 1 and 100 in serial fashion (1,2,3 4, etc.) such that initial nodes are less than their corresponding terminal nodes.
11-15	Integer	Terminal Node: represents the terminal node to which the head of an activity connects. Same restrictions as above.
16-20	Integer	Man-Hours of Work: represents the man-hours of work estimated to work an activity. For constraints (dummies, etc.) which, by definition, require no work, this variable should be zero.

21-25	Integer	Standard Cost: represents the direct labor costs to work an activity on a standard manning basis. This would be obtained by the estimator by multiplying the estimated standard man-hours of work by the cost per man-hour.
26-30	Integer	Crash Cost: represents the direct labor costs to work an activity on a crash manning basis. In most cases, crashing the work-rate results in a higher cost than working it on a standard basis due to declining worker productivity. This figure should be estimated with care since it directly influences the rate at which an entire project is worked.
31-32	Integer	Skill 1 Requirements: Conveys how many workers of skill 1 are required by an activity to work it on a standard manning basis. For constraints, when the value of man-hours of work is zero, this variable conveys to the program the number of half days of lag on a standard basis which are involved.
33-34	Integer	Skill 1 Requirements: same as above except on a crash basis.
35-36	Integer	Skill 2 Requirements: conveys how many workers of skill 2 are required by an activity to work it on a standard basis.
37-38	Integer	Skill 2 Requirements: same as above except on a crash basis.
39-40	Integer	Skill 3 Requirements: same as above except on a standard basis.

41-42	Integer	Skill 3 Requirements: same as above except on a crash basis.
43-44	Integer	Skill 4 Requirements: same as above except on a standard basis.
45-46	Integer	Skill 4 Requirements: same as above except on a crash basis.
47-48	Integer	Skill 5 Requirements: same as above except on a standard basis.
49-50	Integer	Skill 5 Requirements: same as above except on a crash basis.

6.2 Revised Projects

If a change in a project is required, the complete re-engineered project must be resubmitted. To do this, delete obsolete or completed activity cards from the original input deck and add new or revised cards as required. Submit the new deck to the computer with any other new input projects. The same project identification number must be used in order to delete the old project data from the carryover tape.

6.3 Input Data Sequence

All original input data must be read into the computer in the following sequence:

(1) Master Schedule Parameter card
(2) Project Identification card for project A
(3) Activity Data cards for project A
(4) Blank card
(5) Project Identification card for project N
(6) Activity Data cards for project N
(7) Blank card
(8) Project Identification card for last project
(9) Activity Data cards for last project
(10) Blank card
(11) Blank card

The blank card between projects signifies that all activities in that project have been read. The extra blank card at the end of the new program input signifies that all projects have been read. It is obvious, then, that neither a project identification number nor an activity identification number can be zero.

To economize on computer time, the new input data should be transferred to Tape Unit 4 off-line. If project carryover is involved, the carryover tape should be placed on Tape Unit 10.

CHAPTER 7

PRINTED PROGRAM OUTPUT

7.1 General

The program generates sufficient output to furnish top management and the Master Scheduler with Long Range Schedule information and complete project summaries, to furnish the lead shop with detailed working schedules for each project, and to list detailed master schedule information for the use of the entire labor force.

7.2 Long Range Schedule

This schedule lists information for each project worked on each half day of the schedule range specified. A separate page is prepared for each morning and afternoon of each day, and appropriately labeled with the schedule range, the total manpower availability, and the actual number of men scheduled to work. The following information is furnished for each project:

(1) Identification number
(2) Start
(3) Finish
(4) Total Man-Hours of work required
(5) Man-Hours Remaining to be worked
(6) Average Men Working
(7) Scheduled Men/Day

7.3 Project Summary

The project summary lists all projects submitted to the program in their order of working and gives engineering (CPM) output data and cost data for use by the scheduler

and the engineers.

The following is listed for each project:

(1) Identification Number
(2) Total Number of Activities
(3) Total Man-Hours of work required
(4) Start
For unscheduled projects, words "NOT SCHEDULED"
(5) Finish
(6) Working Time (Duration)
(7) Direct Labor Costs
(8) Economic Value (Loss/Day)
(9) Direct Labor Costs on Standard Basis
(10) Working Time on Standard Basis
(11) Direct Labor Costs on Crash Basis
(12) Working Time on Crash Basis

7.4 Complete Working Schedule

This listing prepares a complete working schedule for any project worked in the detailed schedule range. The purpose of this output is to provide full CPM data for use by the scheduler, lead shop, and the engineers.

This schedule lists the following for each activity in a project. Each page of output appropriately identifies each project:

(1) Identification Number
(2) Initial Node
(3) Terminal Node
(4) Man-Hours of work required
(5) Total Number of Men required
(6) Direct Labor Cost
(7) Working Time (Duration)
(8) Earliest Start
(9) Earliest Finish
(10) Latest Start
(11) Latest Finish
(12) Total Float
(13) Critical or Not Critical

7.5 Daily Detailed Schedule

This schedule is also prepared for each project and is intended for the use of the lead shop actually responsible for conducting the work. As such, the actual start and finish for each activity in a project is listed. Appropriate titles are printed at the top of each page of output identifying the project and the half day, morning or afternoon, involved.

The following is listed for each activity in each half day of the detailed schedule range:

(1) Identification Number
(2) Initial Node
(3) Terminal Node
(4) Man-Hours of work required
(5) Direct Labor Cost
(6) Working Time (Duration)
(7) Best Start
(8) Best Finish
(9) Total Number of Men required
(10) Number of Men required of each Shop, Skill, or Work Center as desired

7.6 Daily Master Schedule

This final output merges the daily detailed schedules to furnish work information for the use of the entire labor force. All activities being worked in the specific detailed schedule range are listed.by project in ascending order of their start times. The same information is presented for each activity as listed in the Daily Detailed Schedule.

The results for each half day are summarized. The number of men available from each Shop, Skill, or Work Center as well as the actual number of men scheduled are presented.

7.7 Output Coding Scheme

For all computer outputs, the following coding scheme has been developed:

Work tasks or activities commence at the beginning of the half day (morning or afternoon) cited, and terminate at the end of the half day cited. The number to the right of the decimal refers to the half day identified by the integer portion of the number. A (.0) refers to the morning, and a (.5) refers to the afternoon of the day in question.

For example, a project starting on day 1.0 begins in the morning of the first working day. A project ending on day 10.5 terminates at the end of the afternoon of day 10. Thus, if the completion time were 10.0, the project would end at noon on day 10.

CHAPTER 8

CONCLUSIONS

8.1 Summary

The maintenance and/or construction project was first discussed from inception to scheduling within the framework of a system of Controlled Maintenance.

The role of the planner and estimator in preparing the engineering data vital to the scheduling process was explained. CPM was defined and reduced to its essential ingredients, each of which was described in terms of meaning, application, and implementation.

Scheduling was exposed and fully discussed. A digital computer was found to permit more effective utilization of CPM techniques and the economical utilization of human resources.

Three program Chains for CPM and related resource allocation were presented. The techniques and the criteria utilized were explained in some detail. Finally, the required program input format was summarized and the scope, purpose, and format of the output schedules were presented.

8.2 Comments

It can be readily seen by comparing the descriptions in the preceding chapters with the Fortran listing in Appendix B that every programming detail was not discussed. For simplicity and clarity, it was deemed desirable to discuss only the major program techniques.

It is noted that the program's variables were dimensioned such that the maximum

(1) Number of projects = 50
(2) Number of Activities per project = 100
(3) Number of working days per year = 360
(4) Number of Shops, Work Centers, or Skills = 5

These variable dimensions were established arbitrarily keeping in mind the computer memory limitations for each Chain of the program. In fact, the program was logically separated into Chains to provide flexibility in the dimensions of these variables. Therefore, the limits can be varied to suit the needs of a particular user. Of course, this would necessitate slight program indexing revisions.

The approach used in the selection of the decision rules was to seek a good practical working schedule in those cases where the best possible one was precluded by the complexity involved in the use of an exact selection criterion. For example, to assure the establishment of "the" optimum working schedule for the total labor force, given the restriction that projects must be worked within the times determined by their critical paths, all possible combinations of activity schedules would have to be tested. The computer running time required to accomplish this on a problem of much magnitude would be prohibitive. Therefore, an alternate good schedule was sought.

8.3 Conclusions

The three program Chains took approximately four minutes for compilation (translation from FORTRAN coding into machine language). Runs of simple problems were made to test the theory, principles, methods and procedures underlying the program. In addition, these simple problems provided a means of comparing machine performance with hand calculations. In all cases, the evolvement of a manually produced schedule of a caliber equal to that produced by the computer was extremely laborious. Further, what appeared to be a satisfactory schedule before comparison with the machine results, often proved afterward to be nothing more than a random selection of projects and activities with skill requirements similar to those which were available. The greatest difficulty in manual preparation appeared to be keeping track of the different tasks that could be worked. I experienced a great deal of confusion in preparing an overall schedule, until the point of selecting the last few tasks to be worked was reached. Then, the magnitude of the problem had been sufficiently reduced so that it was apparent which skills had been fully utilized. Accordingly, I avoided selecting activities requiring these skills in favor of other tasks.

This experience brings out one of the principal keys to the success of the program. It could predict the effects of individual activity selections on the overall working schedule without having to determine the entire schedule. By using the proportionate shares rule for scheduling tasks, the computer, in essence, reduces the

magnitude of the scheduling problem by proportionally scaling down skill availabilities so that each task is selected as if it were the last one to be worked. By this means, an overall working schedule is determined immediately without having to test a myriad of activity combinations.

On the basis of the test runs, the program appeared to perform as expected. From the basic engineering and cost data furnished for the activities, the program determined the minimum cost, the critical path working schedules for each project, scheduled the project in time, and determined best starting times for the scheduled projects' tasks. Manpower allocations were made within the constraint of the composition of the work force. Several men were assigned out of skill on the last activity scheduled in order to utilize the entire available labor force. As discussed previously, these assignments would have to be checked by the Scheduler, and, if unacceptable, the men could be reassigned to the Work Centers for the accomplishment of minor service and emergency work.

In summation, the program serves to clearly indicate that a computerized resource allocation procedure for maintenance or construction projects, where a constant level of resource use is highly desirable if not required, produces results which are consistently superior to those derived by manual procedures. Further, the underlying concepts of the system of Controlled Maintenance by which a project is systematically planned step by step, uniquely cause the resulting Project Order to be readily adaptable

to use of the Critical Path Method of scheduling.

8.4 Suggestions for Future Work

There are several areas which present interesting possibilities for future work.

One involves modifying this program and its selection rules for actual utilization by a particular organization. The present program, for instance, is only capable of handling a constant labor force for the duration of the scheduling period. In fact, an organization may work multiple shifts each day with different manpower availabilities for each shift. In addition, many of the selection rules are arbitrary and may not serve to optimize the objectives of a particular user.

Another would be incorporating a version of this program into an integrated operating system of Controlled Maintenance. Such a system could produce all management reports, cost control and accounting reports, work performance results, payrolls, and the like. With the use of time sharing[1] and decentralized input/output devices, an integrated program could be used to assign men to new activities and projects on a continuous basis and prepare field orders for working each task. Such a system would constitute a real-time approach and open totally new horizons in the field of Controlled Maintenance.

A third possible area of interest lies in the application of this program for the allocation of fixed resources to the more general case of construction

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[1] Time sharing refers to a computer system whereby a large number of users located at diverse remote locations, simultaneously use a large high speed digital computer to solve their problems.

projects where resources are not so limited. With the advent of time sharing and real-time decision making which permits man-machine communication, a program such as this could be applied to the more general case by the dynamic specification of allowable resource usage limits.

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APPENDIX A

AN EXAMPLE OF THE DETAILED SCHEDULING TECHNIQUE

PROBLEM

Assume: Total men available = 30

Men available, Shop 1 = 12

Men available, Shop 2 = 18

and, Long Range Schedule allocation as follows:

Project Identification	Manpower allocations Day 1 Morning	Day 1 Afternoon
1	15	15
2	15	15

Further assume: that Project 1 has been read into memory and that activity requirements are as follows:

Activity	Men Required	Duration	Shop 1 Req't	Shop 2 Req't
1 (critical)	3	2	2	1
2	3	2	1	2
3	3	2	0	3
4	3	2	3	0
5	3	2	1	2
6	3	2	2	1
7	3	2	0	3

Day 1 - morning has been selected for scheduling.

SOLUTION

Step 1: Determine the number of men of each Shop or Skill working on the half day being scheduled.

Activity 1, critical - 3 men working

proportional share, Shop 1 = 6/5 = (12/30)x3

proportional share, Shop 2 = 9/5 = (18/30)x3

Schedule critical task 1

Men allocated = 15

Men scheduled = 3, 2 of Shop 1, 1 of Shop 2

Shop 1 cumulative difference (CD)
= 6/5 - 10/5 = - 4/5

Shop 2 cumulative difference (CD)
= 9/5 - 5/5 = + 4/5

Step 2: If the number of men scheduled is less than the number allocated, determine the value of the non-critical activities which can be worked.

Activity	Value = $\sum_{1}^{N} \left\lvert W/TWA \times S + CD - WR \right\rvert$
2	6/5
3	4/5
4	26/5
5	6/5
6	16/5
7	4/5

Step 3: Select the non-critical task with the smallest value first encountered by the program and schedule it.

Schedule task 3

Men allocated = 15

Men scheduled = 6, 2 of Shop 1, 4 of Shop 2

Shop 1 CD = 12/5 - 10/5 = + 2/5

Shop 2 CD = 18/5 - 20/5 = -2/5

Repeat Step 2:

Activity	Value
2	6/5
4	14/5
5	6/5
6	4/5
7	16/5

Repeat Step 3:

Schedule task 6

Men allocated = 15

Men scheduled = 9, 4 of Shop 1, 5 of Shop 2

Shop 1 CD = 18/5 - 20/5 = - 2/5

Shop 2 CD = 27/5 - 25/5 = + 2/5

Repeat Step 2:

Activity	Value
2	2/5
4	22/5
5	2/5
7	8/5

Repeat Step 3:

Schedule task 2

Men allocated = 15

Men scheduled = 12, 5 of Shop 1, 7 of Shop 2

Shop 1 CD = 24/5 - 25/5 = - 1/5

Shop 2 CD = 36/5 - 35/5 = + 1/5

Repeat Step 2:

Activity	Value
4	20/5
5	0
7	10/5

Repeat Step 3:

Schedule task 5

Men allocated = 15

Men scheduled = 15, 6 of Shop 1, 9 of Shop 2

Shop 1 CD = 30/5 - 30/5 = 0

Shop 2 CD = 45/5 - 45/5 = 0

The entire manpower allocation for Project 1 has now been used for the first half day. No new activities would be scheduled for the afternoon since all tasks take 2 half days to work and working tasks utilize the entire manpower allocation.

It can be seen that Project 1 used its proportional share of the two skills, 6 men from Shop 1 and 9 men from Shop 2.

APPENDIX B

FORTRAN PROGRAM LISTING

On the pages following is a complete listing of the Fortran program described in this thesis.

No effort has been made to explain the Fortran coding system since this information is readily available in the reference manuals cited in the bibliography.

A partial glossary of names assigned to program variables is included below in the order in which they appear in the program.

Variable Name	Description
I	Activity initial node
J	Activity terminal node
JAIDN	Activity identification
JAMHS	Activity man-hours of work
JASMN	Activity standard work force
JACMN	Activity crash work force
JATMN	Activity actual work force used
JASMH	Activity standard man-hours
JACMH	Activity crash man-hours
JATMH	Activity actual man-hours used
JASCO	Activity standard labor cost
JACCO	Activity crash labor cost
JATCO	Activity actual labor cost
JAEET	Activity early start
JALTE	Activity late finish
JABST	Activity best (actual) start
JABFI	Activity best (actual) finish
AMARC	Activity opportunity cost
JASSK	Activity standard skill requirement
JACSK	Activity crash skill requirement

IPDMA	Project manpower allocation
MSKIL	Skill or Shop availability
IPMON	Project control
IPROS	Number of projects
MSCHS	Schedule start
MLRSR	Long range schedule range
MDDSR	Detailed schedule range
MWDPY	Working days per year
MWHPD	Working hours per day
MSNYS	Schedule new year shift
MTAP2	Carryover tape control
IPSLC	Project standard labor cost
IPCLC	Project crash labor cost
IPACT	Number of project activities
ILARN	Number of largest network node
IPIDN	Project identification
IPLPD	Project economic value
IPTMH	Project total man-hours of work
IPSMH	Project standard man-hours
IPAMH	Project actual man-hours
IPALC	Project actual direct labor cost
IPCMH	Project crash man-hours
IPSST	Project start scheduled
IPSFI	Project finish scheduled
PHREM	Project man-hours of work remaining
IPAVG	Project average men working
IPAVR	Project average men working remaining
IPORD	Project working order priority
OPSAV	Opportunity cost per man

IPAVA	Men available
MDAY	Work day
MLREN	Long range schedule end
MSCH	Men scheduled
PROST	Project start
PROFI	Project finish
PROTM	Project working time (duration)
PRONT	Project standard work time
PROCT	Project crash work time
JARST	Activity restricted start

```
C     A COMPUTER PROGRAM FOR SHOP SCHEDULING OF MAINTENANCE AND CONSTRUC
C      TION PROJECTS. PROGRAM PART I--DETERMINING THE CRITICAL PATH FOR
C      EACH PROJECT AND THE MOST ECONOMICAL WORKING SCHEDULE.
C
      REWIND 8
      REWIND 9
      REWIND 10
C
      DIMENSION I(100),J(100),JAIDN(100),JAMHS(100),JASMN(100),JACMN(100
     1),JATMN(100),JASMH(100),JACMH(100),JATMH(100),JASCO(100),JACCO(100
     2),JATCO(100),JAEET(100),JALTE(100),JABST(100),JABFI(100),AMARC(100
     3),JASSK(100,5),JACSK(100,5),IPDMA(360),MSKIL(5),NUMB(50)
C     INITIALIZATION
      IPMON=0
      KEY=0
      IPROS=0
      DO 12 K=1,360
   12 IPDMA(K)=0
      READ INPUT TAPE 4,11,MSCHS,MLRSR,MDDSR,MWDPY,MWHPD,MSNYS,MTAP2,(MS
     1KIL(M),M=1,5)
   11 FORMAT (12I4)
      WRITE TAPE 9,MSCHS,MLRSR,MDDSR,MWDPY,MWHPD,MSNYS,MTAP2,(MSKIL(M),M
     1=1,5)
      WHPD=MWHPD
   15 IPSLC=0
      IPCLC=0
      IPACT=0
      JLARN=0
      READ INPUT TAPE 4,16,IPIDN,IPLPD
   16 FORMAT (2I5)
      IF (IPIDN) 17,84,17
   17 IPROS=IPROS+1
      NUMB(IPROS)=IPIDN
   18 READ INPUT TAPE 4,19,I1,I2,I3,I4,I5,I6,J1,J2,J3,J4,J5,J6,J7,J8,J9,
     1J10
   19 FORMAT (6I5,10I2)
      IF (I1) 20,21,20
   20 IPACT=IPACT+1
      JAIDN(IPACT)=I1
      I(IPACT)=I2
      J(IPACT)=I3
      JAMHS(IPACT)=I4
      JASCO(IPACT)=I5
      JACCO(IPACT)=I6
      JASSK(IPACT,1)=J1
      JACSK(IPACT,1)=J2
      JASSK(IPACT,2)=J3
      JACSK(IPACT,2)=J4
      JASSK(IPACT,3)=J5
      JACSK(IPACT,3)=J6
      JASSK(IPACT,4)=J7
      JACSK(IPACT,4)=J8
      JASSK(IPACT,5)=J9
      JACSK(IPACT,5)=J10
      GO TO 18
   21 DO 26 K=1,IPACT
      IPSLC=IPSLC+JASCO(K)
      IF (JLARN-I(K)) 23,24,24
   23 JLARN=I(K)
```

```
24 IF (JLARN-J(K)) 25,26,26
25 JLARN=J(K)
26 CONTINUE
27 IPTMH=0
28 DO 40 K=1,IPACT
   IF (JAMHS(K)) 30,29,30
29 JACMH(K)=JACSK(K,1)
   JASMH(K)=JASSK(K,1)
   JASMN(K)=0
   JACMN(K)=0
   JACSK(K,1)=0
   JASSK(K,1)=0
   GO TO 37
30 IPTMH=IPTMH+JAMHS(K)
   JASMN(K)=0
   JACMN(K)=0
   DO 31 J=1,5
   JASMN(K)=JASMN(K)+JASSK(K,J)
31 JACMN(K)=JACMN(K)+JACSK(K,J)
   ATIM=JAMHS(K)
   WRKRS=JACMN(K)
   VALUE1=ATIM/(0.5*WHPD*WRKRS)
   IVALUE=VALUE1
   VALUE2=IVALUE
   VALUE3=VALUE1-VALUE2
   IF (VALUE3-0.5) 32,33,33
32 JACMH(K)=IVALUE
   GO TO 34
33 JACMH(K)=IVALUE+1
34 WRKRS=JASMN(K)
   VALUE1=ATIM/(0.5*WHPD*WRKRS)
   IVALUE=VALUE1
   VALUE2=IVALUE
   VALUE3=VALUE1-VALUE2
   IF (VALUE3-0.5) 35,36,36
35 JASMH(K)=IVALUE
   GO TO 37
36 JASMH=IVALUE+1
37 COSTS=JASCO(K)
   COSTC=JACCO(K)
   IF (JASMH(K)-JACMH(K)) 38,38,39
38 AMARC(K)=COSTC
   GO TO 40
39 TIMES=JASMH(K)
   TIMEC=JACMH(K)
   AMARC(K)=(COSTC-COSTS)/(TIMES-TIMEC)
40 CONTINUE
   MM=0
22 JAEET(1)=0
   DO 47 K=1,JLARN
   KPLUS=K+1
   JAEET(KPLUS)=0
   DO 47 M=1,IPACT
   IF (J(M)-KPLUS) 47,41,47
41 IF (I(M)-K) 42,42,47
42 NODEI=I(M)
   IF (AMARC(M)) 44,43,43
43 JTEST=JAEET(NODEI)+JASMH(M)
   GO TO 45
```

```
44 JTEST=JAEET(NODEI)+JACMH(M)
45 IF (JTEST-JAEET(KPLUS)) 47,47,46
46 JAEET(KPLUS)=JTEST
47 CONTINUE
   JALTE(JLARN)=JAEET(JLARN)-1
   JNOD=JLARN-1
   DO 54 M=1,JNOD
   KMINUS=JLARN-M
   JALTE(KMINUS)=JALTE(JLARN)
   DO 54 N=1,IPACT
   IF (I(N)+M-JLARN) 54,48,54
48 IF (J(N)+M-1-JLARN) 54,49,49
49 NODEJ=J(N)
   IF (AMARC(N)) 51,50,50
50 JTEST=JALTE(NODEJ)-JASMH(N)
   GO TO 52
51 JTEST=JALTE(NODEJ)-JACMH(N)
52 IF(JTEST-JALTE(KMINUS)) 53,54,54
53 JALTE(KMINUS)=JTEST
54 CONTINUE
   IF (MM) 74,55,57
55 MM=1
   INWCST=IPSLC
   IPALC=IPSLC
   IPSMH=JAEET(JLARN)
   IPAMH=JAEET(JLARN)
   ITOTAL=IPALC+((IPAMH*IPLPD)/2)
   DO 56 M=1,IPACT
   JATMN(M)=JASMN(M)
   JATCO(M)=JASCO(M)
56 JATMH(M)=JASMH(M)
   GO TO 62
57 IPPSTM=JAEET(JLARN)
   IPSCST=INWCST+((IPPSTM*IPLPD)/2)
   IF (ITOTAL-IPSCST) 62,58,58
58 IPALC=INWCST
   IPAMH=IPPSTM
   ITOTAL=IPSCST
   DO 61 J=1,IPACT
   IF (AMARC(J)) 59,60,60
59 JATMN(J)=JACMN(J)
   JATCO(J)=JACCO(J)
   JATMH(J)=JACMH(J)
   GO TO 61
60 JATMN(J)=JASMN(J)
   JATCO(J)=JASCO(J)
   JATMH(J)=JASMH(J)
61 CONTINUE
62 OPT=IPSLC
   KLAST=0
   DO 66 M=1,IPACT
   IF (AMARC(M)) 66,63,63
63 NODEI=I(M)
   NODEJ=J(M)
   IF (JAEET(NODEI)+JASMH(M)-JALTE(NODEJ)-1) 66,64,66
64 TEST=AMARC(M)
   IF (OPT-TEST) 66,66,65
65 OPT=TEST
   MAX=M
```

```
      KLAST=1
   66 CONTINUE
      IF (KLAST) 67,68,67
   67 AMARC(MAX)=-AMARC(MAX)
      INWCST=INWCST+JACCO(MAX)-JASCO(MAX)
      GO TO 22
   68 IPCMH=IPPSTM
      IPCLC=INWCST
      MM=-1
      DO 73 N=1,IPACT
      IF (JATMH(N)-JACMH(N)) 70,70,71
   70 IF (AMARC(N)) 73,72,72
   71 IF (AMARC(N)) 72,73,73
   72 AMARC(N)=-AMARC(N)
   73 CONTINUE
      GO TO 22
   74 DO 75 N=1,IPACT
      NODEI=I(N)
      NODEJ=J(N)
      JABST(N)=JAEET(NODEI)
      JABFI(N)=JALTE(NODEJ)
      JAEET(N)=JABST(N)
      JALTE(N)=JABFI(N)
   75 JABST(N)=JABFI(N)+1-JATMH(N)
      IPSST=(4*MWDPY)+1
      IPSFI=IPSST+IPAMH-1
      PHREM=IPTMH
      WRITE TAPE 9,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH
     1,IPSMH,IPCMH,IPSST,IPSFI,IPMON
      DO 77 N=1,IPAMH
      I1=IPDMA(N)
   77 WRITE TAPE 9,I1
      WRITE TAPE 8,IPIDN,IPACT
      DO 83 N=1,IPACT
      IF (AMARC(N)) 105,106,106
  105 IF (JATCO(N)-JACCO(N)) 81,80,80
  106 IF (JATCO(N)-JASCO(N)) 81,81,80
   80 WRITE TAPE 8,JAIDN(N),I(N),J(N),JAMHS(N),JATCO(N),JATMN(N),JATMH(N
     1),JAEET(N),JALTE(N),JABST(N),JABFI(N),(JACSK(N,M),M=1,5)
      GO TO 83
   81 WRITE TAPE 8,JAIDN(N),I(N),J(N),JAMHS(N),JATCO(N),JATMN(N),JATMH(N
     1),JAEET(N),JALTE(N),JABST(N),JABFI(N),(JASSK(N,M),M=1,5)
   83 CONTINUE
      KEY=KEY+1
      GO TO 15
   84 IF (MTAP2) 98,85,98
   85 READ TAPE 10,NOLD
      DO 97 N=1,NOLD
      READ TAPE 10,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH
     1,IPSMH,IPCMH,IPSST,IPSFI,IPMON,(IPDMA(M),M=1,IPAMH),(JAIDN(M),I(M)
     2,J(M),JAMHS(M),JATCO(M),JATMN(M),JATMH(M),JAEET(M),JALTE(M),JABST(
     3M),JABFI(M),(JACSK(M,K),K=1,5),M=1,IPACT)
      IF (MSNYS) 87,88,87
   87 IPSST=IPSST-(2*MWDPY)
      IPSFI=IPSFI-(2*MWDPY)
   88 MSTAD=(2*MSCHS)-1
      IF (IPSFI-MSTAD) 97,89,89
   89 IF (IPSST-MSTAD) 92,90,90
   90 IPSST=(4*MWDPY)+1
```

```
      IPSFI=IPSST+IPAMH-1
      DO 91 M=1,IPAMH
   91 IPDMA(M)=0
   92 MM=0
      DO 94 M=1,IPROS
      IF (IPIDN-NUMB(M)) 94,93,94
   93 MM=1
   94 CONTINUE
      IF (MM) 97,95,97
   95 WRITE TAPE 9,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH
     1,IPSMH,IPCMH,IPSST,IPSFI,IPMON
      DO 96 M=1,IPAMH
      I1=IPDMA(M)
   96 WRITE TAPE 9,I1
      WRITE TAPE 8,IPIDN,IPACT
      DO 99 M=1,IPACT
   99 WRITE TAPE 8,JAIDN(M),I(M),J(M),JAMHS(M),JATCO(M),JATMN(M),JATMH(M
     1),JAEET(M),JALTE(M),JABST(M),JABFI(M),(JACSK(M,N),N=1,5)
      KEY=KEY+1
   97 CONTINUE
   98 END FILE 9
      END FILE 8
C
      REWIND 8
      REWIND 10
C
      WRITE TAPE 10,KEY
      DO 100 K=1,KEY
      READ TAPE 8,IPIDN,IPACT
      DO 101 M=1,IPACT
  101 READ TAPE 8,JAIDN(M),I(M),J(M),JAMHS(M),JATCO(M),JATMN(M),JATMH(M)
     1,JAEET(M),JALTE(M),JABST(M),JABFI(M),(JACSK(M,N),N=1,5)
      WRITE TAPE 10,IPIDN
  100 WRITE TAPE 10,(JAIDN(M),I(M),J(M),JAMHS(M),JATCO(M),JATMN(M),JATMH
     1(M),JAEET(M),JALTE(M),JABST(M),JABFI(M),(JACSK(M,N),N=1,5),M=1,IPA
     2CT)
      END FILE 10
      CALL CHAIN (2,3)
      END
```

```
C      PROGRAM PART II--ALLOCATING TOTAL MANPOWER TO PRIORITY PROJECTS.
C       THIS PART OUTPUTS A PROJECT SUMMARY AND A LONG RANGE SCHEDULE.
C
      REWIND 8
      REWIND 9
      REWIND 10
C
      DIMENSION IPIDN(51),IPLPD(51),IPACT(51),IPALC(51),IPSLC(51),IPCLC(
     151),IPTMH(51),PHREM(51),IPAMH(51),IPSMH(51),IPCMH(51),IPSST(51),IP
     2SFI(51),IPMON(51),IPDMA(50,360),IPAVG(50),IPAVR(50),IPORD(50),OPSA
     3V(50),MSKIL(5)
      COMMON IPDMA
C     INITIALIZATION
      IPAVA=0
      MA=0
      READ TAPE 10,IPROS
      READ TAPE 9,MSCHS,MLRSR,MDDSR,MWDPY,MWHPD,MSNYS,MTAP2,(MSKIL(M),M=
     11,5)
      DO 17 M=1,IPROS
      READ TAPE 9,I1,I2,I3,I4,I5,I6,I7,P1,I8,I9,I10,I11,I12,I13
      IPIDN(M)=I1
      IPLPD(M)=I2
      IPACT(M)=I3
      IPALC(M)=I4
      IPSLC(M)=I5
      IPCLC(M)=I6
      IPTMH(M)=I7
      PHREM(M)=P1
      IPAMH(M)=I8
      IPSMH(M)=I9
      IPCMH(M)=I10
      IPSST(M)=I11
      IPSFI(M)=I12
      IPMON(M)=I13
   15 IPTIM=IPAMH(M)
      DO 17 N=1,IPTIM
      READ TAPE 9,I1
   17 IPDMA(M,N)=I1
      REWIND 9
      WHPD=MWHPD
      MSTRT=(2*MSCHS)-1
      DO 19 M=1,IPROS
      PLPD=IPLPD(M)
      PTMH=IPTMH(M)
      PAMH=IPAMH(M)
      PAVG=PTMH/(0.5*WHPD*PAMH)
      OPSAV(M)=PLPD/PAVG
      IPAVG(M)=PAVG
      SAVG=IPAVG(M)
      IF (PAVG-SAVG-0.25) 19,19,18
   18 IPAVG(M)=IPAVG(M)+1
   19 IPAVR(M)=IPAVG(M)
      KEYA=0
      DO 22 M=1,IPROS
      IF (MSTRT-IPSST(M)) 22,21,21
   21 KEYA=KEYA+1
      IPORD(KEYA)=M
      OPSAV(M)=-OPSAV(M)
   22 CONTINUE
```

```
23 IF (IPROS-KEYA) 28,28,24
24 OPT=-100.0
   DO 27 M=1,IPROS
   IF (OPSAV(M)) 27,25,25
25 IF (OPSAV(M)-OPT) 27,27,26
26 OPT=OPSAV(M)
   NUMB=M
27 CONTINUE
   KEYA=KEYA+1
   IPORD(KEYA)=NUMB
   OPSAV(NUMB)=-OPSAV(NUMB)
   GO TO 23
28 DO 29 M=1,5
29 IPAVA=IPAVA+MSKIL(M)
   MLREN=MSCHS+MLRSR-1
   MPTIM=MSTRT+(2*MLRSR)-1
   DO 66 M=MSTRT,MPTIM
   L=0
   MSCH=0
   PM=M
30 L=L+1
   IF (IPROS-L) 38,31,31
31 NUMB=IPORD(L)
   IF (IPSFI(NUMB)-M) 30,32,32
32 IF (MSCH+IPAVR(NUMB)-IPAVA) 33,33,38
33 MSCH=MSCH+IPAVR(NUMB)
   IF (IPSST(NUMB)-M) 37,37,36
36 IPSST(NUMB)=M
   IPSFI(NUMB)=IPSST(NUMB)+IPAMH(NUMB)-1
37 JDAY=M+1-IPSST(NUMB)
   IPDMA(NUMB,JDAY)=IPAVR(NUMB)
   PAVR=IPAVR(NUMB)
   PHREM(NUMB)=PHREM(NUMB)-(0.5*PAVR*WHPD)
   GO TO 30
38 LPTIM=L-1
39 KEY2=0
   DO 45 N=1,LPTIM
   IF (IPAVA-MSCH) 45,45,40
40 NUMB=IPORD(N)
   IF (IPSFI(NUMB)-M) 45,45,41
41 PSFI=IPSFI(NUMB)
   REMPH=(PHREM(NUMB)-(0.5*WHPD))/(PSFI-PM)
   AVR=IPAVG(NUMB)
   PAMH=IPAMH(NUMB)
   PAVR=REMPH/(0.5*WHPD*(PAMH-PM))
   IF (PAVR-(0.5*AVR)) 45,42,42
42 MSCH=MSCH+1
   IPAVR(NUMB)=PAVR
   SAVG=IPAVR(NUMB)
   IF (PAVR-SAVG-0.25) 44,44,43
43 IPAVR(NUMB)=IPAVR(NUMB)+1
44 PHREM(NUMB)=PHREM(NUMB)-(0.5*WHPD)
   JDAY=M+1-IPSST(NUMB)
   IPDMA(NUMB,JDAY)=IPDMA(NUMB,JDAY)+1
   KEY2=1
45 CONTINUE
   IF (KEY2) 39,46,39
46 MDAY=(PM+1.0)/2.0
   KEY3=25
```

```
   DO 63 K=1,LPTIM
   IF (25-KEY3) 14,14,52
14 IF (MA) 49,47,49
47 WRITE OUTPUT TAPE 2,48,MDAY,MSCHS,MLREN,IPAVA,MSCH
48 FORMAT (1H150X19HLONG RANGE SCHEDULE/50X8HWORK DAYI4,9H  MORNING//
  18X14HSCHEDULE STARTI4,8X12HSCHEDULE ENDI4,21X13HMEN AVAILABLEI5,8X
  213HMEN SCHEDULEDI5///9X7HPROJECT9X7HPROJECT9X7HPROJECT9X5HTOTAL9X9
  3HMAN HOURS9X7HAVERAGE9X9HSCHEDULED/10X6HNUMBER11X5HSTART10X6HFINIS
  4H5X9HMAN HOURS9X9HREMAINING5X11HMEN WORKING11X7HMEN/DAY)
   GO TO 51
49 WRITE OUTPUT TAPE 2,50,MDAY,MSCHS,MLREN,IPAVA,MSCH
50 FORMAT (1H150X19HLONG RANGE SCHEDULE/49X8HWORK DAYI4,11H  AFTERNOO
  1N//8X14HSCHEDULE STARTI4,8X12HSCHEDULE ENDI4,21X13HMEN AVAILABLEI5
  2,8X13HMEN SCHEDULEDI5///9X7HPROJECT9X7HPROJECT9X7HPROJECT9X5HTOTAL
  39X9HMAN HOURS9X7HAVERAGE9X9HSCHEDULED/10X6HNUMBER11X5HSTART10X6HFI
  4NISH5X9HMAN HOURS9X9HREMAINING5X11HMEN WORKING11X7HMEN/DAY)
51 KEY3=0
52 NUMB=IPORD(K)
   IF (IPSFI(NUMB)-M) 63,53,53
53 KEY3=KEY3+1
   JDAY=M+1-IPSST(NUMB)
   ISTRT=IPSST(NUMB)
   IF (ISTRT) 54,54,55
54 ISTRT=ISTRT+(2*MWDPY)
   GO TO 57
55 IF (ISTRT-(2*MWDPY)) 57,57,56
56 ISTRT=ISTRT-(2*MWDPY)
57 STRT=ISTRT+1
   PROST=STRT/2.0
   IFINI=IPSFI(NUMB)
   IF (IFINI) 58,58,59
58 IFINI=IFINI+(2*MWDPY)
   GO TO 61
59 IF (IFINI-(2*MWDPY)) 61,61,60
60 IFINI=IFINI-(2*MWDPY)
61 FINI=IFINI+1
   PROFI=FINI/2.0
   WRITE OUTPUT TAPE 2,62,IPIDN(NUMB),PROST,PROFI,IPTMH(NUMB),PHREM(N
  1UMB),IPAVG(NUMB),IPDMA(NUMB,JDAY)
62 FORMAT (1H0I14,2F16.1,I14,F18.1,I15,I17)
63 CONTINUE
   IF (MA) 65,64,65
64 MA=1
   GO TO 66
65 MA=0
66 CONTINUE
   KEY3=25
   DO 83 K=1,IPROS
   IF (25-KEY3) 67,67,70
67 WRITE OUTPUT TAPE 2,68
68 FORMAT (1H152X15HPROJECT SUMMARY///3X7HPROJECT2X7HPROJECT4X5HTOTAL
  12X7HPROJECT2X7HPROJECT2X7HWORKING3X6HDIRECT3X7HPROJECT2X9HSTD LABO
  2R2X8HSTD WORK2X11HCRASH LABOR2X8HCRASH WK/4X6HNUMBER6X3HACT3X6HMAN
  3HRS4X5HSTART3X6HFINISH5X4HTIME4X5HCOSTS2X8HLOSS/DAY6X5HCOSTS6X4HTI
  4ME8X5HCOSTS6X4HTIME)
   KEY3=0
70 KEY3=KEY3+1
   NUMB=IPORD(K)
   ISTRT=IPSST(NUMB)
```

```
      IF (ISTRT) 71,71,72
   71 ISTRT=ISTRT+(2*MWDPY)
      GO TO 74
   72 IF (ISTRT-(2*MWDPY)) 74,74,73
   73 ISTRT=ISTRT-(2*MWDPY)
   74 STRT=ISTRT+1
      PROST=STRT/2.0
      IFINI=IPSFI(NUMB)
      IF (IFINI) 75,75,76
   75 IFINI=IFINI+(2*MWDPY)
      GO TO 78
   76 IF (IFINI-(2*MWDPY)) 78,78,77
   77 IFINI=IFINI-(2*MWDPY)
   78 FINI=IFINI+1
      PROFI=FINI/2.0
      CRASH=IPCMH(NUMB)
      PROCT=CRASH/2.0
      STD=IPSMH(NUMB)
      PRONT=STD/2.0
      ATIM=IPAMH(NUMB)
      PROTM=ATIM/2.0
      IF (IPSST(NUMB)-(4*MWDPY)) 79,79,81
   79 WRITE OUTPUT TAPE 2,80,IPIDN(NUMB),IPACT(NUMB),IPTMH(NUMB),PROST,P
     1ROFI,PROTM,IPALC(NUMB),IPLPD(NUMB),IPSLC(NUMB),PRONT,IPCLC(NUMB),P
     2ROCT
   80 FORMAT (1H0319,3F9.1,I9,I10,I11,F10.1,I13,F10.1)
      GO TO 83
   81 WRITE OUTPUT TAPE 2,82,IPIDN(NUMB),IPACT(NUMB),IPTMH(NUMB),PROTM,I
     1PALC(NUMB),IPLPD(NUMB),IPSLC(NUMB),PRONT,IPCLC(NUMB),PROCT
   82 FORMAT (1H0319,4X15HNOT SCHEDULED  F9.1,I9,I10,I11,F10.1,I13,F10.1
     1)
   83 CONTINUE
      WRITE TAPE 9,MSCHS,MLRSR,MDDSR,MWDPY,MWHPD,MSNYS,MTAP2,(MSKIL(M),M
     1=1,5),(IPORD(M),M=1,IPROS)
      DO 85 M=1,IPROS
      I1=IPIDN(M)
      I2=IPLPD(M)
      I3=IPACT(M)
      I4=IPALC(M)
      I5=IPSLC(M)
      I6=IPCLC(M)
      I7=IPTMH(M)
      P1=PHREM(M)
      I8=IPAMH(M)
      I9=IPSMH(M)
      I10=IPCMH(M)
      I11=IPSST(M)
      I12=IPSFI(M)
      I13=IPMON(M)
      WRITE TAPE 9,I1,I2,I3,I4,I5,I6,I7,P1,I8,I9,I10,I11,I12,I13
      IPTIM=IPAMH(M)
      DO 85 N=1,IPTIM
      I1=IPDMA(M,N)
   85 WRITE TAPE 9,I1
      END FILE 9
      CALL CHAIN (3,3)
      END
```

```
C     PROGRAM PART III--DETERMINING ACTIVITY EVENT TIMES TO UTILIZE THE
C      AVAILABLE WORK FORCE. THIS PART OUTPUTS COMPLETE AND DETAILED
C      PROJECT WORKING SCHEDULES.
C
      REWIND 8
      REWIND 9
      REWIND 10
C
      DIMENSION IPJDN(200),JAIDN(200),I(200),J(200),JAMHS(200),JATMN(200
     1),JATMH(200),JATCO(200),JAEET(150),JALTE(150),JABST(150),ABSA(200)
     2,JABFI(150),ABFA(200),JASKL(150,5),IPDMA(360),IPORD(50),MSKIL(5),S
     3KILM(5),MSKL1(200),MSKL2(200),MSKL3(200),MSKL4(200),MSKL5(200),BTI
     4ME(200),ABA(5),ABB(5),ABC(720,5),LENT(720),JARST(150),MENS(50),MSC
     5H(720)
      READ TAPE 10,IPROS
      READ TAPE 9,MSCHS,MLRSR,MDDSR,MWDPY,MWHPD,MSNYS,MTAP2,(MSKIL(M),M=
     11,5),(IPORD(M),M=1,IPROS)
      WDPY=MWDPY
      DO 25 M=1,IPROS
      READ TAPE 9,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH,
     1IPSMH,IPCMH,IPSST,IPSFI,IPMON
      DO 16 N=1,IPAMH
      READ TAPE 9,I1
   16 IPDMA(N)=I1
      IF (IPROS-M) 18,17,18
   17 REWIND 9
   18 READ TAPE 10,NUMB
      IF (IPIDN-NUMB) 19,21,19
   19 WRITE OUTPUT TAPE 2,20,IPIDN,NUMB
   20 FORMAT (1H122X28HINFORMATION OUT OF SEQUENCE.3X15HPROJECT NUMBER I
     15,3X16HSCHEDULE NUMBER I5)
      GO TO 25
   21 READ TAPE 10,(JAIDN(K),I(K),J(K),JAMHS(K),JATCO(K),JATMN(K),JATMH(
     1K),JAEET(K),JALTE(K),JABST(K),JABFI(K),(JASKL(K,L),L=1,5),K=1,IPAC
     2T)
      IF (IPROS-M) 24,23,24
   23 REWIND 10
   24 WRITE TAPE 8,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH
     1,IPSMH,IPCMH,IPSST,IPSFI,IPMON,(IPDMA(K),K=1,IPAMH),(JAIDN(K),I(K)
     2,J(K),JAMHS(K),JATCO(K),JATMN(K),JATMH(K),JAEET(K),JALTE(K),JABST(
     3K),JABFI(K),(JASKL(K,L),L=1,5),K=1,IPACT)
   25 CONTINUE
      END FILE 8
C
      REWIND 8
      REWIND 9
      REWIND 10
C
      IPAVA=0
      DO 26 M=1,5
      IPAVA=IPAVA+MSKIL(M)
   26 SKILM(M)=MSKIL(M)
      PAVA=IPAVA
      MSTRT=(2*MSCHS)-1
      MPTIM=MSTRT+(2*MDDSR)-1
      MDDEN=MSCHS+MDDSR-1
C     INITIALIZATION
      DO 27 M=MSTRT,MPTIM
      LENT(M)=0
```

```
      MSCH(M)=0
      DO 27 L=1,5
   27 ABC(M,L)=0
      DO 28 K=1,50
   28 MENS(K)=0
      WRITE TAPE 10,IPROS
      KSCH=0
   29 KEY2=0
      KSCH=KSCH+1
      NUMB=IPORD(KSCH)
      DO 120 L=1,IPROS
      IF (KEY2) 120,30,120
   30 READ TAPE 8,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH,
     1IPSMH,IPCMH,IPSST,IPSFI,IPMON,(IPDMA(M),M=1,IPAMH),(JAIDN(K),I(K),
     2J(K),JAMHS(K),JATCO(K),JATMN(K),JATMH(K),JAEET(K),JALTE(K),JABST(K
     3),JABFI(K),(JASKL(K,N),N=1,5),K=1,IPACT)
      IF (NUMB-L) 120,31,120
   31 IF (IPSST-MPTIM) 33,33,32
   32 KEY2=-1
      GO TO 120
   33 IF (IPSST-JAEET(1)) 36,38,34
   34 KD=IPSST-JAEET(1)
      DO 35 K=1,IPACT
      JAEET(K)=JAEET(K)+KD
      JALTE(K)=JALTE(K)+KD
      JABST(K)=JABST(K)+KD
   35 JABFI(K)=JABFI(K)+KD
      GO TO 38
   36 KD=JAEET(1)-IPSST
      DO 37 K=1,IPACT
      JAEET(K)=JAEET(K)-KD
      JALTE(K)=JALTE(K)-KD
      JABST(K)=JABST(K)-KD
   37 JABFI(K)=JABFI(K)-KD
   38 MENS(KSCH)=IPIDN
      DO 13 K=1,IPACT
      JARST(K)=IPSST
      IF (JAEET(K)+JATMH(K)-JALTE(K)-1) 40,39,40
   39 JARST(K)=JAEET(K)
      GO TO 13
   40 DO 43 M=1,IPACT
      IF (J(M)-I(M)) 43,41,43
   41 IPM=JABFI(M)+1
      IF (JARST(K)-IPM) 42,43,43
   42 JARST(K)=IPM
   43 CONTINUE
   13 CONTINUE
      DO 67 M=MSTRT,MPTIM
      MPR=0
      DO 46 K=1,IPACT
      IF (M-JABST(K)) 46,44,44
   44 IF (JABFI(K)-M) 46,45,45
   45 MSCH(M)=MSCH(M)+JATMN(K)
      MPR=MPR+JATMN(K)
      REN=JATMN(K)
      DO 12 N=1,5
      ASKL=JASKL(K,N)
      ABC(M,N)=ABC(M,N)+((REN*SKILM(N))/PAVA)-ASKL
   12 CONTINUE
```

```
46 CONTINUE
   MDAY=M+1-IPSST
65 IF (IPDMA(MDAY)-IPMON-LENT(M)-MPR) 66,66,47
47 BST=100.0
   JOB=0
   DO 56 K=1,IPACT
   IF (M-JARST(K)) 56,48,48
48 IF (JABST(K)-M) 56,56,49
49 REN=JATMN(K)
   COUNT=0
   IF (MSCH(M)+JATMN(K)-IPAVA) 50,50,56
50 DO 53 N=1,5
   ASKL=JASKL(K,N)
   ABA(N)=ABC(M,N)+((REN*SKILM(N))/PAVA)-ASKL
   IF (ABA(N)) 51,52,52
51 COUNT=COUNT-ABA(N)
   GO TO 53
52 COUNT=COUNT+ABA(N)
53 CONTINUE
   IF (BST-COUNT) 56,56,54
54 DO 55 N=1,5
55 ABB(N)=ABA(N)
   JOB=K
56 CONTINUE
   IF (JOB) 57,66,57
57 MSCH(M)=MSCH(M)+JATMN(JOB)
   MPR=MPR+JATMN(JOB)
   JABST(JOB)=M
   JABFI(JOB)=JABST(JOB)+JATMN(JOB)-1
   ND=J(JOB)
   DO 58 K=1,5
58 ABC(M,K)=ABC(M,K)+ABB(K)
   DO 11 N=1,IPACT
   IF (ND-I(N)) 11,59,11
59 JARST(N)=IPSST
   IF (JAEET(N)+JATMH(N)-JALTE(N)-1) 61,60,61
60 JARST(N)=JAEET(N)
   GO TO 11
61 DO 64 K=1,IPACT
   IF (J(K)-I(K)) 64,62,64
62 IPM=JABFI(K)+1
   IF (JARST(N)-IPM) 63,64,64
63 JARST(N)=IPM
64 CONTINUE
11 CONTINUE
   GO TO 65
66 IPMON=MPR-IPDMA(MDAY)
   LENT(M)=LENT(M)+MPR-IPDMA(MDAY)
67 CONTINUE
   KEY3=25
   ISTRT=IPSST
   IF (ISTRT) 68,68,70
68 ISTRT=ISTRT+(2*MWDPY)
   GO TO 72
70 IF (ISTRT-(2*MWDPY)) 72,72,71
71 ISTRT=ISTRT-(2*MWDPY)
72 STRT=ISTRT+1
   PROST=STRT/2.0
   IFINI=IPSFI
```

```
   IF (IFINI) 73,73,74
73 IFINI=IFINI+(2*MWDPY)
   GO TO 76
74 IF (IFINI-(2*MWDPY)) 76,76,75
75 IFINI=IFINI-(2*MWDPY)
76 FINI=IFINI+1
   PROFI=FINI/2.0
   ATIM=IPAMH
   PROTM=ATIM/2.0
   WRITE TAPE 10,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAM
  1H,IPSMH,IPCMH,IPSST,IPSFI,IPMON,(IPDMA(K),K=1,IPAMH),(JAIDN(K),I(K
  2),J(K),JAMHS(K),JATCO(K),JATMN(K),JATMH(K),JAEET(K),JALTE(K),JABST
  3(K),JABFI(K),(JASKL(K,N),N=1,5),K=1,IPACT)
   DO 92 N=1,IPACT
   IF (25-KEY3) 77,77,79
77 WRITE OUTPUT TAPE 2,78,IPIDN,PROST,PROFI,PROTM,IPTMH
78 FORMAT (1H146X25HCOMPLETE WORKING SCHEDULE/50X14HPROJECT NUMBERI5/
  1/6X14HPROJECT START F5.1,8X11HPROJECT ENDF6.1,19X12HWORKING TIMEF5
  2.1,10X12HTOTAL MANHRSI6//7X3HACT3X4HINIT3X4HTERM4X3HMAN3X5HTOTAL3X
  35HLABOR3X7HWORKING3X8HEARLIEST3X8HEARLIEST3X6HLATEST3X6HLATEST3X5H
  4TOTAL3X8HACTIVITY/4X6HNUMBER3X4HNODE3X4HNODE4X3HHRS5X3HMEN4X4HCOST
  56X4HTIME6X5HSTART5X6HFINISH4X5HSTART3X6HFINISH3X5HFLOAT3X8HCATEGOR
  6Y)
   KEY3=0
79 KEY3=KEY3+1
   ERL=JAEET(N)+1
   AEET=ERL/2.0
   IF (AEET) 80,80,81
80 AEET=AEET+WDPY
   GO TO 83
81 IF (AEET-WDPY-0.5) 83,83,82
82 AEET=AEET-WDPY
83 AFTER=JALTE(N)+1
   AFTFI=AFTER/2.0
   IF (AFTFI) 84,84,85
84 AFTFI=AFTFI+WDPY
   GO TO 87
85 IF (AFTFI-WDPY-0.5) 87,87,86
86 AFTFI=AFTFI-WDPY
87 ATIM=JATMH(N)
   ATIME=ATIM/2.0
   AERF=AEET+ATIME-0.5
   AFTST=AFTFI+0.5-ATIME
   FLOAT=AFTFI+0.5-AEET-ATIME
   IF (JAEET(N)+JATMH(N)-JALTE(N)-1) 90,88,90
88 WRITE OUTPUT TAPE 2,89,JAIDN(N),I(N),J(N),JAMHS(N),JATMN(N),JATCO(
  1N),ATIME,AEET,AERF,AFTST,AFTFI,FLOAT
89 FORMAT (1H0I9,3I7,2I8,F10.1,2F11.1,2F9.1,F8.1,3X8HCRITICAL)
   GO TO 92
90 WRITE OUTPUT TAPE 2,91,JAIDN(N),I(N),J(N),JAMHS(N),JATMN(N),JATCO(
  1N),ATIME,AEET,AERF,AFTST,AFTFI,FLOAT
91 FORMAT (1H0I9,3I7,2I8,F10.1,2F11.1,2F9.1,F8.1,3X8HNOT CRIT)
92 CONTINUF
   MA=0
   DO 150 M=MSTRT,MPTIM
   PM=M
   MDAY=(PM+1.0)/2.0
   KEY3=25
   DO 116 K=1,IPACT
```

```
      IF (25-KEY3) 93,93,100
   93 IF (MA) 96,94,96
   94 WRITE OUTPUT TAPE 2,95,MDAY,IPIDN,MSCHS,MDDEN
   95 FORMAT (1H148X23HDAILY DETAILED SCHEDULE/48X11HDAY NUMBER I4,3X7HM
     1ORNING//21X15HPROJECT NUMBER I5,10X15HSCHEDULE START I4,10X13HSCHE
     2DULE END I4///)
      GO TO 98
   96 WRITE OUTPUT TAPE 2,97,MDAY,IPIDN,MSCHS,MDDEN
   97 FORMAT (1H148X23HDAILY DETAILED SCHEDULE/47X11HDAY NUMBER I4,3X9HA
     1FTERNOON//21X15HPROJECT NUMBER I5,10X15HSCHEDULE START I4,10X13HSC
     2HEDULE END I4///)
   98 WRITE OUTPUT TAPE 2,99
   99 FORMAT (1H+4X3HACT3X4HINIT3X4HTERM3X3HMAN3X5HLABOR3X7HWORKING4X4HB
     1EST5X4HBEST3X5HTOTAL3X6HSHOP 13X6HSHOP 23X6HSHOP 33X6HSHOP 43X6HSH
     2OP 5/5X3HNO.3X4HNODE3X4HNODE3X3HHRS4X4HCOST6X4HTIME3X5HSTART3X6HFI
     3NISH5X3HMEN6X3HMEN6X3HMEN6X3HMEN6X3HMEN6X3HMEN)
      KEY3=0
  100 IF (M-JABST(K)) 116,101,101
  101 IF (JABFI(K)-M) 116,102,102
  102 KEY3=KEY3+1
      JOB=JAIDN(K)
      IF (JOB) 103,104,104
  103 JOB=-JOB
  104 ATIM=JATMH(K)
      ATIME=ATIM/2.0
      INIT=I(K)
      JTER=J(K)
      IHR=JAMHS(K)
      ICT=JATCO(K)
      IMN=JATMN(K)
      MS1=JASKL(K,1)
      MS2=JASKL(K,2)
      MS3=JASKL(K,3)
      MS4=JASKL(K,4)
      MS5=JASKL(K,5)
      STRT=JABST(K)+1
      ABST=STRT/2.0
      IF (ABST) 105,105,106
  105 ABST=ABST+WDPY
      GO TO 108
  106 IF (ABST-WDPY-0.5) 108,108,107
  107 ABST=ABST-WDPY
  108 FINAL=JABFI(K)+1
      ABFI=FINAL/2.0
      IF (ABFI) 109,109,110
  109 ABFI=ABFI+WDPY
      GO TO 112
  110 IF (ABFI-WDPY-0.5) 112,112,111
  111 ABFI=ABFI-WDPY
  112 WRITE OUTPUT TAPE 2,113,JOB,I(K),J(K),JAMHS(K),JATCO(K),ATIME,ABST
     1,ABFI,JATMN(K),MS1,MS2,MS3,MS4,MS5
  113 FORMAT (1H0317,I6,I8,F10.1,F8.1,F9.1,I8,5I9)
      IF (JAIDN(K)) 116,114,114
  114 WRITE TAPE 9,IPIDN,JOB,INIT,JTER,IHR,ICT,ATIME,ABST,ABFI,IMN,MS1,M
     1S2,MS3,MS4,MS5
      JAIDN(K)=-JAIDN(K)
  116 CONTINUE
      IF (MA) 152,151,152
  151 MA=1
```

```
      GO TO 150
  152 MA=0
  150 CONTINUE
      IF (KSCH-50) 118,117,117
  117 KEY2=-1
      GO TO 120
  118 INT=KSCH+1
      JNT=IPORD(INT)
      IF (NUMB-JNT) 120,119,119
  119 KEY2=1
  120 CONTINUE
      REWIND 8
      IF (KEY2) 121,29,29
  121 IPIDN=0
      WRITE TAPE 9,IPIDN,JOB,INIT,JTER,IHR,ICT,ATIME,ABST,ABFI,IMN,MS1,M
     1S2,MS3,MS4,MS5
      END FILE 9
      DO 125 L=1,IPROS
      READ TAPE 8,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAMH,
     1IPSMH,IPCMH,IPSST,IPSFI,IPMON,(IPDMA(K),K=1,IPAMH),(JAIDN(K),I(K),
     2J(K),JAMHS(K),JATCO(K),JATMN(K),JATMH(K),JAEET(K),JALTE(K),JABST(K
     3),JABFI(K),(JASKL(K,N),N=1,5),K=1,IPACT)
      KEY2=0
      DO 123 N=1,50
      IF (IPIDN-MENS(N)) 123,122,123
  122 KEY2=1
  123 CONTINUE
      IF (KEY2) 125,124,125
  124 WRITE TAPE 10,IPIDN,IPLPD,IPACT,IPALC,IPSLC,IPCLC,IPTMH,PHREM,IPAM
     1H,IPSMH,IPCMH,IPSST,IPSFI,IPMON,(IPDMA(K),K=1,IPAMH),(JAIDN(K),I(K
     2),J(K),JAMHS(K),JATCO(K),JATMN(K),JATMH(K),JAEET(K),JALTE(K),JABST
     3(K),JABFI(K),(JASKL(K,M),M=1,5),K=1,IPACT)
  125 CONTINUE
      END FILE 10
      REWIND 9
      KEY4=0
  127 READ TAPE 9,I1,I2,I3,I4,I5,I6,P1,P2,P3,I7,I8,I9,I10,I11,I12
      IF (I1) 128,129,128
  128 KEY4=KEY4+1
      IPJDN(KEY4)=I1
      JAIDN(KEY4)=I2
      I(KEY4)=I3
      J(KEY4)=I4
      JAMHS(KEY4)=I5
      JATCO(KEY4)=I6
      BTIME(KEY4)=P1
      ABSA(KEY4)=P2
      ABFA(KEY4)=P3
      JATMN(KEY4)=I7
      MSKL1(KEY4)=I8
      MSKL2(KEY4)=I9
      MSKL3(KEY4)=I10
      MSKL4(KEY4)=I11
      MSKL5(KEY4)=I12
      GO TO 127
  129 MA=0
      DO 146 M=MSTRT,MPTIM
      PM=M
      DAY=(PM+1.0)/2.0
```

```
      MDAY=DAY
      KEY3=25
      MSCHA=0
      MEN1=0
      MEN2=0
      MEN3=0
      MEN4=0
      MEN5=0
      DO 141 L=1,KEY4
      IF (25-KEY3) 130,130,137
  130 IF (MA) 133,131,133
  131 WRITE OUTPUT TAPE 2,132,MDAY,MSCHS,MDDEN
  132 FORMAT (1H149X21HDAILY MASTER SCHEDULE/48X11HDAY NUMBER I4,3X7HMOR
     1NING//30X15HSCHEDULE START I4,21X13HSCHEDULE END I4///)
      GO TO 135
  133 WRITE OUTPUT TAPE 2,134,MDAY,MSCHS,MDDEN
  134 FORMAT (1H149X21HDAILY MASTER SCHEDULE/47X11HDAY NUMBER I4,3X9HAFT
     1ERNOON//30X15HSCHEDULE START I4,21X13HSCHEDULE END I4///)
  135 WRITE OUTPUT TAPE 2,136
  136 FORMAT (1H+3X7HPROJECT3X3HACT3X4HINIT3X4HTERM3X3HMAN3X5HLABOR3X4HW
     1ORK4X4HBEST5X4HBEST3X5HTOTAL3X5HSHOP13X5HSHOP23X5HSHOP33X5HSHOP43X
     25HSHOP5/5X6HNUMBER3X3HNO.3X4HNODE3X4HNODE3X3HHRS4X4HCOST3X4HTIME3X
     35HSTART3X6HFINISH5X3HMEN5X3HMEN5X3HMEN5X3HMEN5X3HMEN5X3HMEN)
      KEY3=0
  137 IF (DAY-ABSA(L)) 141,138,138
  138 IF (ABFA(L)-DAY) 141,139,139
  139 KEY3=KEY3+1
      WRITE OUTPUT TAPE 2,140,IPJDN(L),JAIDN(L),I(L),J(L),JAMHS(L),JATCO
     1(L),BTIME(L),ABSA(L),ABFA(L),JATMN(L),MSKL1(L),MSKL2(L),MSKL3(L),M
     2SKL4(L),MSKL5(L)
  140 FORMAT (1H0I10,I6,2I7,I6,I8,F7.1,F8.1,F9.1,6I8)
      MSCHA=MSCHA+JATMN(L)
      MEN1=MEN1+MSKL1(L)
      MEN2=MEN2+MSKL2(L)
      MEN3=MEN3+MSKL3(L)
      MEN4=MEN4+MSKL4(L)
      MEN5=MEN5+MSKL5(L)
  141 CONTINUE
      IF (MA) 143,142,143
  142 MA=1
      GO TO 144
  143 MA=0
  144 WRITE OUTPUT TAPE 2,145,IPAVA,MSKIL(1),MSKIL(2),MSKIL(3),MSKIL(4),
     1MSKIL(5),MSCHA,MEN1,MEN2,MEN3,MEN4,MEN5
  145 FORMAT (1H052X16HMEN AVAILABLE...6I8/53X16HMEN SCHEDULED...6I8)
  146 CONTINUE
C
      REWIND 8
      REWIND 9
      REWIND 10
C
      CALL EXIT
      END
```

APPENDIX C

EXCERPTS FROM INPUT DATA
AND
COMPUTER OUTPUT

SAMPLE INPUT DATA

```
                            CARD COLUMN
1   5    1    1    2    2    3 3 3 3 3 4 4 4 4 4 5
         0    5    0    5    0 2 4 6 8 0 2 4 6 8 0


 230  40  20 240   8   1   0  20  16  24  12  18   MASTER SCH. PARAMETERS
  100   10                                         PROJECT IDENTIFICATION
   11    1    2    8   20   24 1 2     1 2         ACT. ENGINEERING DATA
   12    1    4    8   20   24         1 2
   13    1    5    8   20   24 1 2
   14    2    3    8   20   24 1 2     1 2
   15    3    6    8   20   24         1 2
   16    4    5    8   20   24         1 2
   17    5    6    8   20   24 1 2     1 2
   18    6    7    8   20   24 1 2     1 2
                                                   BLANK CARD
  101   20                                         PROJECT IDENTIFICATION
    1    1    2   30   70   95 2 3 1 2 1 2 2 3     ACT. ENGINEERING DATA
    2    2    3    4   12   16         1 2
    3    2    4   14   40   50 2 3 2 3 1 2     1 2
    4    3    5   50  125  150 4 6 1 2 2 3 3 5
    5    4    5   12   30   36 2 3     1 2     1 2
                                                   BLANK CARD
  102   35                                         PROJECT IDENTIFICATION
   50    1    2   12   30   40 1 2     1 2         ACT. ENGINEERING DATA
   51    1    3   24   55   70     2 3     4 6
   52    1    7   16   38   56         1 2     2 3
   53    2    4    8   24   30     1 2
   54    2    5    4   10   15         1 2
   55    3    4   18   36   45 2 3             1 2
   56    4    5   36   80  100     3 5     2 3 1 2
   57    4    7   25   40   60         1 2     2 3
   58    5    6   40  100  125 1 2 2 3 3 5 4 6 1 2
   59    6    7   44  116  140     7 9     3 5
   60    7    8   50  130  165 2 3 5 7 3 5     1 2
   61    7    9   55  142  168         6 8 2 3 3 5
   62    8    9   10   30   42 1 2 1 2
   63    9   10   22   62   75 2 3     3 4 1 2
                                                   BLANK CARD
                                                   BLANK CARD
```

```
                                       LONG RANGE SCHEDULE
                                      WORK DAY 100  MORNING

SCHEDULE START 100     SCHEDULE END 101             MEN AVAILABLE 6      MEN SCHEDULED 6

 PROJECT   PROJECT    PROJECT       TOTAL   MAN HOURS        AVERAGE    SCHEDULED
  NUMBER     START     FINISH   MAN HOURS   REMAINING    MEN WORKING      MEN/DAY
   100       100.0     102.0          64       52.0             3            3
   101       100.0     102.0          64       52.0             3            3
```

```
                         LONG RANGE SCHEDULE
                        WORK DAY 100  AFTERNOON

SCHEDULE START 100    SCHEDULE END 101      MEN AVAILABLE 6    MEN SCHEDULED 6

  PROJECT    PROJECT    PROJECT        TOTAL    MAN HOURS        AVERAGE    SCHEDULED
   NUMBER      START     FINISH    MAN HOURS    REMAINING    MEN WORKING      MEN/DAY
    100        100.0     102.0           64       40.0             3            3
    101        100.0     102.0           64       40.0             3            3
```

```
                                PROJECT SUMMARY

PROJECT PROJECT  TOTAL PROJECT PROJECT WORKING DIRECT  PROJECT STD LABOR STD WORK CRASH LABOR CRASH WK
 NUMBER     ACT MANHRS   START  FINISH    TIME  COSTS LOSS/DAY     COSTS     TIME       COSTS     TIME

   100       8     64   100.0   102.0     2.5    164      10       160      3.0         192      2.0
   101       8     64   100.0   102.0     2.5    164      10       160      3.0         192      2.0
```

```
                              COMPLETE WORKING SCHEDULE

                                 PROJECT NUMBER 100

PROJECT START 100.0        PROJECT END 102.0         WORKING TIME 2.5        TOTAL MANHRS  64

   ACT  INIT  TERM  MAN  TOTAL  LABOR  WORKING  EARLIEST  EARLIEST  LATEST  LATEST  TOTAL  ACTIVITY
NUMBER  NODE  NODE  HRS    MEN   COST     TIME     START    FINISH   START  FINISH  FLOAT  CATEGORY
    11     1     2    8      2     20       .5     100.0     100.0   100.0   100.0     0.  CRITICAL
    12     1     4    8      2     24       .5     100.0     100.0   100.0   100.0     0.  CRITICAL
    13     1     5    8      1     20      1.0     100.0     100.5   100.5   101.0     .5  NOT CRIT
    14     2     3    8      2     20       .5     100.5     100.5   100.5   100.5     0.  CRITICAL
    15     3     6    8      1     20      1.0     101.0     101.5   101.0   101.5     0.  CRITICAL
    16     4     5    8      1     20      1.0     100.5     101.0   100.5   101.0     0.  CRITICAL
    17     5     6    8      2     20       .5     101.5     101.5   101.5   101.5     0.  CRITICAL
    18     6     7    8      2     20       .5     102.0     102.0   102.0   102.0     0.  CRITICAL
```

```
                              DAILY DETAILED SCHEDULE
                              DAY NUMBER 100    MORNING

        PROJECT NUMBER 100         SCHEDULE START 100         SCHEDULE END 101

ACT  INIT  TERM  MAN  LABOR  WORKING   BEST    BEST  TOTAL  SHOP 1  SHOP 2  SHOP 3  SHOP 4  SHOP 5
NO.  NODE  NODE  HRS   COST     TIME  START  FINISH    MEN     MEN     MEN     MEN     MEN     MEN
 11     1     2    8     20       .5  100.0   100.0      2       1       0       1       0       0
 12     1     4    8     24       .5  100.0   100.0      2       0       0       2       0       0
```

```
                                    DAILY MASTER SCHEDULE
                                 DAY NUMBER 101   MORNING

         SCHEDULE START 100                                     SCHEDULE END 101

PROJECT  ACT  INIT  TERM  MAN  LABOR  WORK   BEST    BEST   TOTAL  SHOP 1  SHOP 2  SHOP 3  SHOP 4  SHOP 5
 NUMBER  NO.  NODE  NODE  HRS   COST  TIME  START  FINISH    MEN     MEN     MEN     MEN     MEN     MEN
    100   13     1     5    8     20   1.0  100.5   101.0      1       1       0       0       0       0
    100   16     4     5    8     20   1.0  100.5   101.0      1       0       0       1       0       0
    101   23     1     5    8     20   1.0  100.5   101.0      1       0       0       1       0       0
    101   26     4     5    8     20   1.0  100.5   101.0      1       1       0       0       0       0
    100   15     3     6    8     20   1.0  101.0   101.5      1       0       0       1       0       0
    100   25     3     6    8     20   1.0  101.0   101.5      1       1       0       0       0       0

                                        MEN AVAILABLE ... 6      3       0       3       0       0
                                        MEN SCHEDULED ... 6      3       0       3       0       0
```

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